ELEMENTARY FOREST MENSURATION

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BY

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WITH A CHAPTER ON
THE MEASUREMENT OF FORESTS

BY

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LONDON: THOMAS MURBY & CO., 1, FLEET LANE, E.C.4
1939

PRINTED IN GREAT BRITAIN
BY
THE WOODBRIDGE PRESS, LTD., GUILDFORD.

PREFACE

THIS book is primarily intended for the instruction of British university and college students who intend to take up forestry as a profession, though the requirements of serving foresters have also been borne in mind. Since the publication of the 5th edition of Schlich's Manual, Volume III—now out of print—no book, so far as the writer is aware, has appeared with this purpose in view, and the need for such is, he believes, widely felt. The title " Elementary " is given in view of the fact that the author deals very briefly with certain subjects, which, though they may be of fundamental importance to the specialist and research worker, are not, in his opinion, part of the essential equipment of every professional forester.

Thus the importance of sampling in forest mensuration suggests the desirability of a pre-study of the science of statistics, and this is no doubt required by directors of research. For the ordinary purposes of forest management, however, intelligence in the selection of samples is of more importance than the ability to apply a mathematical test to the adequacy of their number. The maximum number of samples which can be taken in any particular case depends primarily on economic considerations, and a small increase in their number does not necessarily increase the reliability of the result. Likewise the importance in forest mensuration of indirect estimate demands on the part of the specialist a much more thorough study of graphic methods of representing data than is provided for in this book. Again, an intensive study of the technique of ring counting and measurement is required for the *accurate* analysis of tree stems, and is essential for those who would use the information obtainable from this source for such purposes as tracing variations and changes of climate.

To require from every forest student a thorough knowledge of the above subjects would, in the author's opinion, impose an undesirable burden. Those to whom such knowledge is essential are already catered for elsewhere. American authors, in particular Bruce and Schumacher (9)*, have treated the subjects of statistics and graphs from the forester's point of view and relieved him from dependence on general literature for their study, whilst the technique of ring counting and measuring can be studied in Douglas and Pearson's " Tree Ring Analysis " (12).

* Figures in parentheses refer to the List of Works on p. ix.

Chapter IX has been contributed by Mr. R. Bourne, late lecturer on Forestry in the Forest School of the University of Oxford, and the author is also much indebted to his notes for assistance in the other chapters of this book. In compiling the portions of Chapters IV and V dealing with form-class taper and volume tables, the author has made considerable use of the work carried out on behalf of the Forestry Commission by Mr. James Macdonald, who has also very kindly checked this part of the manuscript. The author is grateful to Lady Schlich for her permission to make use of the late Sir William Schlich's work, Volume III of the latter's manual having been freely drawn upon. Finally he wishes to acknowledge the great assistance he has received from the criticisms and suggestions of Mr. T. Thomson, Head of the Department of Forestry at the University College of North Wales, Bangor.

BANGOR M. R. K. J.
January, 1939

CONTENTS

LIST OF WORKS REFERRED TO

The numbers given are the reference numbers used in the text.

1. Schlich's Manual of Forestry, Vol. III.
2. Measurements of the Cubical Contents of Forest Crops. M. D. Chaturvedi. Oxford Forestry Memoir No. 4 of 1926.
3. The Expression of Stem Form. Dr. M. L. Anderson. Scottish Forestry Journal, Vol. 41, 1927.
4. The Measurement of Standing Trees. James Macdonald. Scottish Forestry Journal, Vol. 45, 1931.
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6. Form Class Taper Curves and Volume Tables. C. E. Behre. U.S.A. Journal of Agricultural Research, Vol. 35, 1927.
7. Forest Measurement, 1931. H. C. Belyea. Chapman and Hall, London.
8. Elements of Forest Mensuration. Chapman and Demeritt. 1932. J. B. Lyon Co., Albany, New York.
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10. Growth and Yield of Conifers in Great Britain. British Forestry Commission Bulletin No. 10. H.M. Stationery Office.
11. The Theory of Forest Types. A. J. Cajander. English reprint from Acta Forestalia Fennica 31.
12. Problems and Methods of Tree Ring Analysis. A. E. Douglas and G. A. Pearson. Carnegie Institution of Washington.
13. Volume Yield Tables, Money Yield Tables, Volume and Form-factor Tables for Teak Plantations in Madras. R. Bourne, M.A. Government Printing Press, Calcutta.
14. A Textbook on Forest Management. M. R. K. Jerram. Chapman and Hall, London.

LIST OF ABBREVIATIONS

B.F.C.	British Forestry Commission
B.H. or b.h.	Breast height
C.A.I.	Current annual increment
D. or d.	Diameter
D.B.H. or d.b.h.	,, at breast height
F. or f.	Form Factor
F.H. or f.h.	Form height
f.q.	Form quotient
G. or g.	Girth
G.B.H. or g.b.h.	,, at breast height
H. or h.	Height
M.A.I.	Mean annual increment
O.B. or o.b.	Over bark
P.M.A.I.	Periodical mean annual increment
Q.G. or q.g.	Quarter girth
Q.G.B.H. or q.g.b.h.	,, ,, at breast height
r.	Radius
S. or s. (basal area is sometimes written S.B.H. or s.b.h where a distinction is necessary)	Sectional area of a tree or log, or basal area if measured at breast height
U.B. or u.b.	Under bark
V. or v.	Volume

CHAPTER I

GENERAL HISTORY

Before dealing with the practice of forest mensuration it is desirable that the student should appreciate the objects of this branch of forest science and the manner in which it has grown up in the countries in which forestry was first developed.

Forest mensuration deals with the measurement of forest products, and its requirements must be studied from the points of view both of the producer and the user of these products.

MEASUREMENT FOR PURPOSES OF SALE

In early times accurate measurement was unnecessary to any party. As long as demands were small and the supplies provided by nature ample, values remained too low for the owner to concern himself with anything beyond the roughest form of measurement of what was removed, whilst the user, not being under the necessity of considering economic conversion, was equally unconcerned with the volume measurement of what he obtained.

In Europe, small material such as firewood was sold by the **headload**, and timber by the amount that could be extracted at any one time with a team of oxen or simply by the tree, for which a **stump fee** was paid. With the development of roads and the use of carts, the **cartload** was often employed as the unit of sale, both for timber and fuel. To-day such units are frequently in use in other countries and survive locally, even in Europe, though there they are further defined by weight or by measurement. In Great Britain the unit is in some localities still the load, which may vary from 25 to 40 cubic feet according to the accessibility of the locality.

With increasing values of timber the owner became interested in obtaining a price commensurate with the quantity of material he was selling and, between the producer and the user of the finished product, a class of middlemen grew up whose profits depended on the accuracy with which they were able to estimate in advance the quantity of produce which they would receive for the price paid to the producer. They were concerned

with the total bulk, in so far as it affected labour costs for extraction and conversion and the capacity of their mills; still more, however, were they concerned with the volume of the merchantable material which would be available after conversion.

A natural consequence of this consideration would appear to be the development of methods of measurement, which would provide the basis for a direct estimate of this merchantable material, in place of one which gives the total bulk, which is made up of the former plus a quantity of waste. To a certain extent this has been the case. In most countries one finds *local* methods of measurement adopted with this end in view. Such methods have never become of general application in Europe, but on the North American continent they are almost universally used. There are objections to the general adoption of such methods. It will be appreciated that the measurement of a tree in terms of any product previous to manufacture is only an approximation of the yield which it may be possible to obtain from it. The results will vary from the estimate if the conditions of conversion differ from those on which the estimate is based. Such variations in conditions include the conversion of a log into sawn timber of dimensions other than those provided for by the estimate, varying skill on the part of sawyers and varying gauges of the saws used. These factors will alter the proportion of waste in converting the tree, so that the estimate may be no more accurate than one based on bulk measurement. In the forests of Europe these considerations had additional force from the fact that, from an early date, intensive utilisation was practised; that is to say, a large proportion of the total volume of the tree was converted into merchantable timber of varying dimensions with a comparatively small amount of waste.

It is clear that the more intensive the utilisation the nearer will the outturn approach the total volume of the tree. Moreover, owing to an early recognition of the necessity for conserving forest resources, interest in accurate measurement for sale purposes did not precede interest in such measurement for management purposes, the requirements of which are, as will be shown later, somewhat different. In European practice, therefore, measurement of trees and logs aims generally at determining the approximate volume in the round before conversion.

On the North American continent, on the other hand, the immediate profits to be derived from the exploitation of virgin forests were for a long time the only consideration and a more or less standardised method of utilisation involving a high proportion of waste was generally employed. The standard method

of measurement, adopted, at least in part, as a result of these conditions, is one based on the yield of 1in. thick sawn planks. The unit is one **board** foot, *i.e.* a plank 1 foot square and 1in. thick, and **log rules** —tables giving the contents in board feet of logs of varying diameter and length—are in general use for determining the volumes of trees and logs for both sale and management purposes.

The British **quarter-girth system**, dealt with in Chapter III, represents a compromise between a measurement of total bulk and a measurement of converted produce; it is supposed to determine the quantity of milling timber available after the log has been roughly squared and before the final wastage in sawing into scantlings has taken place.

MEASUREMENT FOR PURPOSES OF MANAGEMENT

As soon as the producer came to realise that he was the possessor of valuable raw material which, though not inexhaustible, was capable by proper management of meeting a continuous demand, he became interested in measurement of his property from a much broader point of view than that represented by the necessity for measuring sale lots.

In the first place, he required to know exactly the extent of his property, a requirement which had to be met by demarcation and mapping; it is customary to deal with this branch of forest mensuration separately under the heading of Forest Surveys. In the second place, he needed to know the quantity of the material standing in the forest, a need met by making inventories of the **Growing Stock,** a subject dealt with in Chapter IX of this book. For this purpose all the trees in a forest above a stated minimum size were enumerated and their volume estimated with the help of **volume tables** (tables giving the volumes of typical trees of different dimensions). In Europe, 100 per cent. enumerations have been the rule. In exceptional cases enumerations have been confined to sample areas—either random samples, parallel strips or partial enumerations of distinct crops previously delimited on maps. In other countries in which the development of forestry has reached this stage, the principles of sampling have generally been applied in consideration of large areas involved.

With the conversion of forests to even-aged stands, such a feature in the last century in European forestry, another method of estimating the volume of the growing stock, by **yield tables,** was devised. Before referring further to this method, however, it is desirable to emphasise that the existing growing stock in a forest only represents the **capital** and, in order to determine the amount of material available for felling, it became necessary for

the producer to determine the productive capacity of the capital or, in other words, the **annual increment.**

For this purpose, from quite early times in the development of forest practice, **sample plots** were selected in different localities, or **site qualities**, and all the trees in them measured at intervals of years. For convenience in determining the **periodic increment,** by comparison of successive measurements, the **thinning cycle** was adopted as the interval between measurements, the trees removed in thinning, or **Intermediate Yield,** being measured separately from those left to grow for the following period, or **Major Yield.**

From the data collected in sample plots, **Yield Tables** (Chapter VIII) were prepared, which set out for different site qualities the stages in the development, from early youth to maturity, of stands of unit area, one hectare or one acre. Such tables were only prepared for regular forests of even-aged or more or less even-aged woods, and were used to estimate not only the increment and probable yields of forests, but also the growing stock. Indeed, in the stock-taking of regular woods, estimates of capital came to be based on yield tables rather than on enumerations and volume tables.

MEASUREMENT FOR PURPOSES OF RESEARCH

In due course producers became interested in estimating in advance the possibility of increasing the amount of production in the future and in determining the treatment and system of management which resulted either in the highest rate of production, or in maximum production of the desired material.

From the results of earlier work, it had come to be realised that the method of thinning greatly influenced the rate of growth and **form** of the trees in a stand. In consequence new series of sample plots were laid out to test the effects of different methods and *grades of thinning.*

Investigation into the rate of growth on small sample areas requires a much more accurate measurement of the individual tree than is necessary for sale and management purposes. The difficulty of accurate measurement lies in the fact—elaborated in the next chapter—that trees are irregular bodies, and recently much research has been undertaken to elucidate the laws governing **form** and to discover methods of measurement of standing trees which take it into account and therefore give accurate results. (See: Form-Class Taper Tables, Chapter IV.)

All such investigations have their value, but it is possible to overestimate the assistance which accurate measurement can give to scientific forest management. Volume production is seldom the only consideration; quality, which cannot be

measured, is often of more importance than quantity, and the silvicultural procedure which will produce the one does not necessarily produce the other.

. . . dreams of any substantial increase in the volume increment as a result of better treatment of the crop have almost completely vanished, since Research Institutes prove on the grounds of 40-50 years' experiments with various methods of treatment that the volume increment cannot be much influenced, assuming, that is, a correctly chosen species and a soil in good condition." Dr. Burger, Director of the Forestry Research Institute, Zürich. (See *Quarterly Journal of Forestry*, Vol. XXXII, 2.) This must, of course, not be taken to imply that the volume increment cannot be reduced *by bad treatment*, but super exact measurements are not required to facilitate distinction between good and bad

CHAPTER II

THE THEORY OF TREE MEASUREMENT

Foresters classify the principal forest trees under the headings of **Broad-leaved** trees and **Conifers.** The former are known botanically as Dicotyledons (from the two cotyledons in the seedling), a sub-division of the Angiospermæ (covered seed) group of flowering plants; the latter represent one of the classes of the Gymnospermæ (naked seed) group of flowering plants. Broad-leaved trees and conifers are therefore wide apart botanically and, consequently, it is not surprising to find that they differ in structure and growth. Such differences affect utilisation and, to some extent, the methods of measurement, which depend on the shape of the body to be measured and the purposes for which it is to be used. The distinctive features which are of practical importance in mensuration are dealt with below.

GENERAL SHAPE

For the purposes of this chapter the tree is considered as that portion of it which is above ground; that is, the **crown** and **stem** (*Fig.* 1). In conifers foresters sometimes distinguish a lower and upper crown, the former starting from the lowest living branch and the latter from the lowest whorl of living branches.

In a typical broad-leaved tree, such as the oak, there is often no clear distinction between the stem and the crown, the former merging into the latter by repeated branching. In a typical conifer, such as the spruce, the stem is visible as a central axis throughout the whole length of the tree. In pines this feature is less marked, and in later years their shape may approach that of the broad-leaved tree type.

Different form-types, due to the condition under which the tree is grown, will also be observed if the low crowned trees of a species, typical of park land, are compared with the high crowned trees in closed woods. Similarly, young trees of a species are often markedly different in form from old trees.

Such differences in form as the above are obvious to the casual observer. There are, however, differences in the shape of trees, of the same species, grown in woods which are not so obvious, but are of importance in influencing the volume content.

These differences depend on the factors affecting the size of the crown and the influence of the latter on the form of the bole and are dealt with later in this chapter.

The difference in form of broad-leaved and coniferous trees, referred to above, affects utilisation and measurement in the following ways. In the former there is generally a *natural* limit to the length of the stem (or bole), which can be used as timber, imposed by the heavy branching in the crown. Thus in *Fig.* 1a

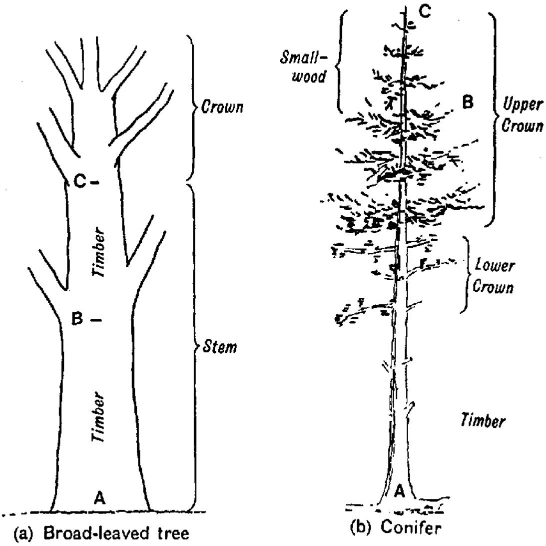


FIG. 1.

the stem will produce one length from A to B and possibly another from B to C; these lengths will be extracted in log and their solid volume measured. The remainder of the tree will be classified as crown wood and, if marketable (or if a knowledge of the *total volume* is required), is usually cut up and measured in stacks. Some of the larger and straighter branches may be measured as timber. In conifers branching does not generally impose a natural limit to the timber length and an arbitrary division of the stem into timber and small-wood is therefore made (*Fig.* 1b). Where timber is being measured for sale the diameter limit depends on market requirements; where it is being measured

for research or management purposes a fixed standard is adopted. The British Forestry Commission (B.F.C.) have fixed 3ins. in diameter over bark as the limit for timber, which corresponds roughly to the 7 centimetre limit fixed in countries using the metric system. The branch wood and *small-wood* of conifers usually represents waste, but, if saleable, it may be dealt with in the same way as the crown wood of broad-leaved trees. If a knowledge of the total volume, or total stem volume, is required for research purposes, the small-wood of the stem is measured as a solid separately from the branches.

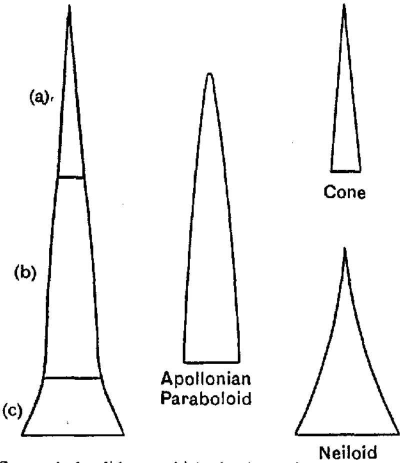


FIG. 2. Geometrical solids to which the form of the stem approximates.

The volume of a solid can be determined readily by calculation from a few simple linear measurements only when the solid has a regular geometrical shape. Trees, however, are irregularly shaped solids for which immersion in a liquid provides the only accurate means of measuring volume (p. 24), a procedure which is, of course, impracticable in ordinary forest operations. All volume measurements of trees are therefore estimates based on linear measurements of regular solid bodies to which they are considered to approximate. *The object of foresters is to standardise and limit errors, so that the results obtained are comparable.**

* For a full discussion of the errors which arise in the measurement of trees see "Measurement of the Cubical Contents of Forest Crops," by Chaturvedi. Oxford Forestry Memoir, No. 4 of 1926.

VARIATIONS IN TAPER

The taper of a tree varies in its several parts which, in consequence, approximate to different geometrical solids.

Thus, in *Fig.* 2 the *top, middle* and *butt* sections of the bole resemble respectively a cone (a), the frustrum of an Apollonian parabaloid (b) and the frustrum of a neiloid (c). In the stem of *broad-leaved trees,* however, sudden differences in taper may occur as a result of side branching; see *Fig.* 1a.

The degree of taper in the several parts of a tree depends on the relation between the crown and the root. A tree growing in an isolated position retains living branches a long way down the bole and has a proportionately large root system. The conical top is relatively long, the truncated neiloid base is pronounced and the central section approximates to a truncated cone as much as to a truncated parabaloid; apart from the basal section, the taper of the bole is fairly constant. On the other hand, a tree growing in a closed wood has its living crown restricted to the top of the bole and a comparatively small root system. The conical top is short and sharply tapering, while the central and basal sections respectively approximate as much to a cylinder as to a truncated parabaloid and a truncated neiloid. These points are illustrated diagrammatically in *Fig.* 3a and b.

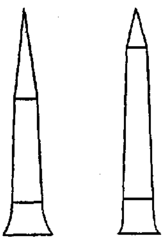

(a) (b)

FIG. 3. Stem-form of a conifer.
(a) Isolated,
(b) Closed crop.

Such variations in the degree of taper can be explained purely on a physiological basis, the translocation of manufactured food materials to the lower part of the bole being more favourable in the case of a tree with its crown spreading well down the stem than with a tree having its crown restricted to the top.

Metzger's theory: Metzger, a German forester, however, evolved a theory, sometimes known as the *girder theory,* that the *stem of a tree is built up in such a way as with the minimum of material to offer uniformly the greatest resistance to the stresses to which it is subjected.* Under most conditions the principal stress to which a tree is subjected is that of the wind, acting mainly through the crown. He observed that trees were generally up-rooted by the wind rather than broken. At the same time, he noted that stems were snapped in phenomenal storms and this led him to suggest that a definite law existed limiting the growth in circumference of the bole at any point.* Subsequent

* For a full discussion of Metzger's theory see "The Structure and Life of Forest Trees." Büshen, Münch, and Thomson.

research by several investigators has tended to corroborate Metzger's contention and their work is now often made use of in measurement for purposes of research.

In practice a stem or log is assumed for the purposes of measurement to have the form of a truncated paraboloid (*Fig.* 2b). The one exception occurs when the complete stem wood is measured; the top section is then assumed to have the shape of a cone. The volume of a cone is obtained from

Formula 1. Volume $= \frac{1}{3}$ (s × l), where s is the sectional area of the base and l the length.

The volume of a truncated paraboloid is equal to the product of its mean sectional area and length, and is obtained from one of two formulæ.

Formula 2. Smalian's. Volume $= \frac{s' + s''}{2} \times l$, where the mean of two end sections is taken,

and

Formula 3. Huber's. Volume $=$ sm × l, where the mid-section is measured.

Huber's formula is generally used in the case of timber, unless it is stacked and the mid-sections are inaccessible. These formulæ give the correct volume of the regular solids to which they relate; when applied to stems of irregular taper various errors may arise, which may in some cases be compensating, particularly when a large quantity of timber is measured.

ECCENTRICITY OF SECTION

The *sectional area* in the above formulæ is a true circle and is calculated from the measured *diameter* (d) or *girth* (g) from formulæ 4 and 5 below.

Formula 4. $s = \frac{\pi d^2}{4}$ or $0{\cdot}785d^2$

(derived from $s = \pi r^2 = \pi\left(\frac{d}{2}\right)^2 = 3{\cdot}1416 \times \frac{d^2}{4}$)

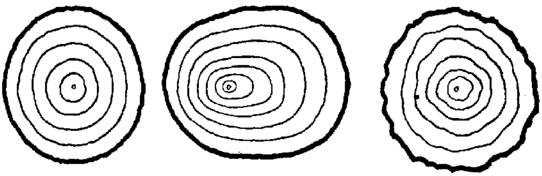
Formula 5. $s = \frac{g^2}{4\pi}$ or $\cdot 0796 g^2$

(derived from $2\pi r = g$ and $r = \frac{g}{2\pi}$

$$s = \pi r^2 = \pi \times \frac{g^2}{4\pi^2} = \frac{g^2}{4\pi} = \frac{g^2}{4 \times 3{\cdot}1416})$$

The stem of a tree, however, is seldom circular in section (*Fig.* 4a) : more often it is elliptic (*Fig.* 4b), and sometimes fluted (*Fig.* 4c).

If the tree is fluted it is obvious that the sectional area calculated from the diameter or girth will be overestimated. If the section is merely elliptical it is clear that the area calculated from the girth is overestimated, since the area of a circle with the perimeter of an ellipse is greater than the area of the ellipse. The same remark applies to the area calculated from a mean diameter, and the error is of course accentuated, if an axis greater than the mean axis of the ellipse is measured; but, if an axis shorter than the mean axis is measured, the error may be partly or wholly counteracted. Consider the case of an ellipse whose major



(a) (b) (c)

FIG. 4. Types of cross-sections of stems.

axis = d, minor axis = d_1, and mean axis = dm. The formula for obtaining the sectional area of the ellipse is

$$s = \pi \left(\frac{d}{2} \times \frac{d_1}{2}\right)$$

Since, however, the calculation of the sectional area in forestry is based on the assumption that the tree section is circular, this formula is never used. The formulæ actually used for obtaining the area from two diameter measurements are either

Formula 6. $$s = \pi\left(\frac{dm}{2}\right)^2 \text{ derived from } s = \pi\left(\frac{\frac{d}{2}+\frac{d_1}{2}}{2}\right)^2$$

or

Formula 7. $$s = \pi \times \frac{\left(\frac{d}{2}\right)^2 + \left(\frac{d_1}{2}\right)^2}{2}$$

Formula 6 gives the sectional area derived from the mean axis, Formula 7 gives the mean of the sectional areas derived from the two axes. The latter will always give a larger area than the former, and, since in any case the errors are likely to be positive, the former is therefore preferable. The positive error involved in calculating the area of the ellipse from the girth (Formula 5) is slightly greater than that given by Formula 6. The middle

sections are usually the most circular, while the lowest (butt) section and top section, immediately below the crown, are the most elliptic. Where fluting occurs it is usually confined to the butt section, particularly when it results from the formation of root buttresses.

Eccentricity in section towards the base of trees is primarily brought about by wind action. Apart from steep slopes on which trees generally produce their largest roots up and down the slope, the main lateral roots of trees tend to develop in the line of the prevailing wind. The effect of this alone may be sufficient to produce elliptic sections to some height on the stem. The stimulus to growth caused by alternating high and low pressures on the cambium, resulting from the swaying of trees in the wind, is, however, a further factor influencing the production of elliptic sections to considerable height on the bole.*

Thus, the precise determination of the *sectional areas* of the boles of trees is fraught with difficulties, particularly towards the base of the stem. For this reason the determination of sectional areas at or towards the base of trees is avoided wherever possible. On felled trees this is relatively easy; on standing trees it is, from a practical point of view, generally impossible. For practical reasons, the sectional areas of standing trees obviously have to be determined, if possible, at a height within reach of a man standing on the ground. On trees with large root buttresses, even this may be impossible. Since the measurer has to use and read the instruments to measure diameters or girths, from which to calculate the sectional areas, the height of measurement must be below eye-level. For this reason and to facilitate comparisons of measurements, these are taken at a fixed height, termed Breast Height, or B.H., and distinguished as D.B.H. or G.B.H. according to whether the diameter or the girth is measured.

In European countries, employing the metric system, breast height has long been fixed at 1·3 metres. In India and the U.S.A. it has been fixed at 4 ft. 6 ins. In the British Isles, the Forestry Commission have adopted 4 ft. 3 ins., as approximately equivalent to 1·3 metres. On sloping ground, breast height is determined on the upper side of the tree. Breast height is, therefore, the greatest height at which the diameter or girth of a standing tree can be conveniently measured and the sectional area corresponding to D.B.H. or G.B.H. is termed the *Basal Area* (S.B.H.).

* That the majority of European trees have an elliptical cross section with the largest axis in the direction of the prevailing wind has been proved by a number of investigations, *e.g.* Chaturvedi (2) quotes the following figures for a beech stand in which every tree was measured.

88·3% had their maximum diameter in E.-W. direction.
9·9% „ „ „ „ „ N.S. „
1·8% were circular.

VARYING BARK THICKNESS

The stem consists of timber and bark. In some trees the bark is so thin as not to affect measurement materially (*e.g.* the Beech). In many species the bark represents a considerable proportion of the total bole volume, and must be separated from the timber, or allowed for, before the volume of the latter can be determined.* The thickness of the bark does not necessarily maintain the same proportion to the diameter of the timber throughout the length of the tree, so that the taper of the bole of the tree *over bark* may be different from the taper of the timber of the tree *under bark*. It is the latter and not the former to which Metzger's theory applies.

CROOKEDNESS

In order to determine the volume of a solid, accurate measurement of length is necessary. This is almost impossible in the case of a crooked stem. In practice the measurement is made in a straight line.

* For bark percentages of some European Species see Appendix I.

CHAPTER III

THE MEASUREMENT OF FELLED TREES AND THEIR OUT-TURN.

Objects of Measurement. — Felled trees are measured in order to determine the quantity of merchantable volume or produce which they contain, and also to obtain statistical data which may be applied to standing trees for the purpose of estimating the yield, capital (growing stock) and increment of woods and forests.

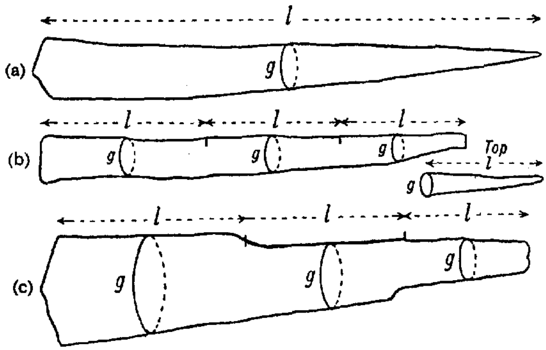


FIG. 5. Division of stem into log-lengths for measurements.

A. DETERMINATION OF MERCHANTABLE VOLUME OR PRODUCE

As has been explained in Chapter II, the tree is separated into stem wood—which may be divided further into timber and small-wood—and crown or branch wood.

1. STEM WOOD

Stem wood may be measured in one length (*Fig.* 5a) or after division into sections (*Fig.* 5b). If the taper is irregular the larger the number of sections the more nearly will the real

volume be obtained. In broad leaved trees there are often sudden alterations in thickness due to branching. The points where these occur are called **stops**. They indicate natural divisions for separating the stem wood into sections (*Fig.* 5c).

The measurements required are length, and mid-diameter or mid-girth, except where the top is measured as a cone when the diameter or girth at the end is measured.

Length. — The length generally excludes any shaped portion of the butt end due to felling with an axe and the measurement may be taken so as to make an allowance for a visible defect such as heart rot. The length may be measured with a tape or a rod : the former is more accurate but requires two men.

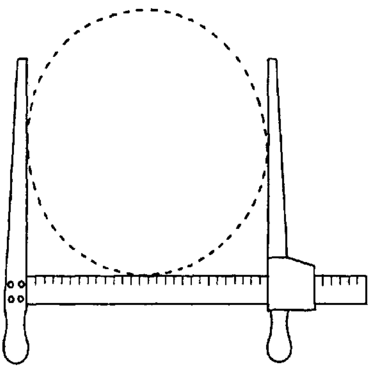


FIG. 6. A calliper.

If a rod is used each rod length should be marked on the stem. In Great Britain the measurement is usually to the nearest foot, sometimes to the nearest ½ or ¼ foot.

Diameter. — The diameter is measured with a calliper (*Fig.* 6). A *calliper* is a graduated rule with two arms, one fixed at one end of the rule and at right angles to it; the other moving along the rule parallel to the former. Each arm should be rather more than half the length of the rule. Many different makes of calliper are in use, varying both in the method of graduation of the rule and in the method used for ensuring that the movable arm shall be parallel to the fixed arm, when the measurement is taken, and yet shall not stick on the rule. Most callipers are constructed of wood. To use the calliper the instrument is held at right angles to the axis of the stem or log with the fixed arm pressed against it; the movable arm is then closed on the tree

and the diameter read on the rule against the inner edge of the former. Where, as is usually the case with logs lying on the ground, the calliper rule cannot be pressed home against the surface, special care is required to ensure that the movable arm is at right angles to the rule. To reduce the chance of error in measuring a short or a long axis, two measurements should be made at right-angles to one another and the mean of the two taken as the correct diameter, which is then used to calculate the sectional area from Formula 4 (p. 10)* or from the tables in Appendix III. The diameter is usually measured to the nearest inch, but in research work often to the nearest 1/10th inch.

Girth. — The girth is measured with a tape which must be stretched in a plane at right angles to the longitudinal axis of the stem. Measurement is usually to the nearest inch, sometimes to the nearest ¼ inch, but often to 1/10th inch in research work. In order to pass the tape under a log lying on the ground it may be necessary to use a piece of bent iron with the tip cut in the form of a hook, or to dig a hole. The sectional area is calculated from the girth by Formula 5 (p. 10)* or obtained from the tables in Appendix IV.

Quarter-Girth.—The quarter-girth, required for the British system of volume measurement (See *quarter-girth volume* below), is measured with a quarter-girth tape or with a cord and 2 foot rule. The quarter-girth tape is a tape graduated in units equivalent to inches and quarter inches to the scale of 1 in. = 4 ins., so that girth readings, when the tape is stretched round the stem, indicate one quarter of the actual girth. If a cord is used, it is folded four times to the mark, and laid along a foot rule to obtain the quarter-girth.†

True Volume. — The volume in *cubic feet* is obtained from the product of the mean sectional-area and length (Formula 3, p. 10) or, where the top is measured as a cone (*Fig.* 5b, p. 14) from the end sectional-area by Formula 1 (p. 10). The tables in Appendix III or IV may be employed. In countries using the decimal system the unit is 1 *cubic metre*.

Quarter-Girth Volume.— In the British Empire, however, there is another unit of measurement, the quarter-girth cubic foot, which is the volume of a cylinder 1 foot long and 4 feet in

* Since diameter and girth are measured in inches and sectional area is expressed in square feet, the figure 144 must be introduced into the denominators of formulæ 4 and 5. Thus $s = \frac{\pi d^2}{4 \times 144}$ or $\frac{g^2}{4\pi \times 144}$.

†It is not always easy to pass a tape or cord under a large log lying in the forest even with the assistance of a piece of bent wire. Much time may be saved by measuring the diameter with a calliper which is graduated to show equivalent quarter-girths. The scale required for graduating a calliper so as to read quarter-girths is given in Appendix V.

girth. The sectional area is obtained from the following formula :—

Formula 8.

$$\text{sectional area} = \left(\frac{g}{4}\right)^2$$

The volume is obtained from

Formula 9.

$$\text{Volume in cubic feet q.g.} = \frac{\left(\frac{\text{girth in inches}}{4}\right)^2 \times \text{length in feet.}}{144}$$

This is the system of measurement used in Great Britain for sale purposes when round timber is sold by volume. The underlying idea is that it gives in cubic feet solid approximately the correct volume after rough squaring of the timber. The stem is visualised as a roughly squared baulk having a side equal to $\frac{1}{4}$ of the girth of the log from which it is obtained. This is, however. a purely imaginary conception; the maximum square obtainable from a circular section has a side equal to $\sqrt{2r^2}$ which is less than $\frac{g}{4}$. Sanctioned by long use the system is universally employed in Great Britain even for research purposes. Since the volume in *quarter-girth cubic feet* bears a constant relationship to the true volume in *cubic feet solid*, figures obtainable by either method are comparable. The quarter-girth cubic foot is a larger unit than the solid cubic foot and the ratio of the former to the latter is 4: 3·1416, as will be seen by comparing Formula 5 (p. 10) with Formula 8. The following conversion factors may be used :—

Formula 10.

$$\text{True volume} = \text{quarter-girth volume} \times \frac{4{\cdot}0000}{3{\cdot}1416} (= 1{\cdot}273)$$

or ,, ,, = ,, ,, $+ 27\frac{1}{2}\%$.

Formula 11.

$$\text{quarter-girth volume} = \text{true volume} \times \frac{3{\cdot}1416}{4{\cdot}0000} (= 0{\cdot}785)$$

or ,, ,, = ,, ,, less $21\frac{1}{2}\%$.

The quarter-girth system of measurement is sometimes known as Hoppus's Rule after Hoppus, who first drew up tables for use with it. A summary of Hoppus's tables will be found in Appendix II. In this table 1 H. (Hoppus) foot is equivalent to 1 square foot, 1 H. inch to 1/12th of 1 H. foot, and one part to 1/12th of 1 H. inch. When multiplied by the length in feet for

cubic measurement, the resulting figures are quarter-girth cubic feet, 1/12ths, and 1/144ths of a quarter-girth cubic foot.

The method of booking the measurements depends upon the requirements of the particular case. The following is an example of how they may be booked for oak in Great Britain.

Nos. of trees	Length of logs	Q.G.	Volume 12 in. and over	Volume Under 12 in.	Volume Total Volume
1	20	16	36		
	12	12	12		
	8	9		4	52
2	22	14¼	31		
	14	8½		7	38

Bark Allowance. — To obtain the correct volume of timber, girth and diameter measurement should be made after the removal of bark. In Great Britain it is customary to measure for sale over bark, and, in the case of rough barked species, such as oak, to make a deduction of 1 in. in the quarter-girth for any quarter-girth up to 12 ins., and ½ in. for each additional 6 ins. quarter-girth.

Thus

17½ ins. becomes 16½ ins. which assumes a bark thickness of $\frac{2}{\pi}$ or 0·64 in.

18 ins. becomes 16½ ins. which assumes a bark thickness of $\frac{3}{\pi}$ or 0·95 in.

24 ins. becomes 22 ins. which assumes a bark thickness of $\frac{4}{\pi}$ or 1·27 in.,

and so on.

This allowance is often excessive; the correct mathematical allowance is 0·3925 in. from the quarter-girth for every ¼ in. of the bark thickness.*

Sources of Error in Volume Measurement of the Stem. —As explained in Chapter II, "plus" errors arise from cross sections not being circular and "plus or minus" errors from the logs not being paraboloid. Moreover, "plus" errors will result if the tape or calliper is not held at right angles to the longitudinal axis of the tree. When using a cord in the quarter-

* This system of bark allowances is gradually being superseded by one under which a percentage is allowed on the o.b. volume. Thus the B.F.C. deduct 10% from the o.b. volume as bark allowance in the case of oak.

girth system, unduly stretching the cord round the log, so that it registers less when released and folded on the rule, or using an unduly thick cord with resulting loss in measurement at the folds will result in minus errors. (N.B.—The cord is only used in measurement for sale purposes and these errors penalise the seller.)

2. Crown and Branch Wood

Wood intended for fuel, and also small crooked pieces which may be used as timber, is stacked for measurement. The units of measurement are as follows:—

In Great Britain, 1 *cord*, generally equivalent to 128 cubic feet stacked.

In India, 100 cubic feet stacked.

In countries using the decimal system 1 cubic metre stacked.

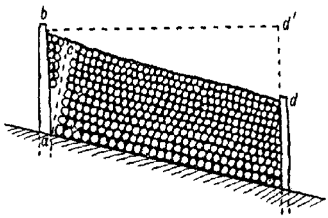


Fig. 7. Stacked measurement on sloping ground.

For convenience in measurement the wood is generally stacked in these units or multiples thereof, the length and height of the stack being governed by the length of the billets. Thus the dimensions of a stack of one cord with billets 4 ft. long might be

8 ft. long × 4 ft. high × 4 ft. wide.

The stack is generally built 3 to 4 inches higher than the required height in order to allow for shrinkage in drying. The length is usually measured with a tape and height with a rod. The volume of the stack in cubic feet is given by the formula

$$\text{Volume} = \text{length} \times \text{breadth} \times \text{height}$$

provided the stack is rectangular. If the stack is built on steeply sloping ground, as in *Fig.* 7, this will not be the case, for the ends cannot be built at right angles to the length. The standard height should then be made ac and not ab or, alternatively, ab and the horizontal distance bd′ may be measured; *i.e.* the pro-

duct of either ac x bd or ab x bd′ and the length of a billet will give the correct volume. The actual quantity of wood which is contained in a cubic foot stacked depends on the shape of the billets, but bad stacking will result in this being very much less than the maximum possible.

3. Bark

When bark is sold separately it is either stacked, and measured as for stacked wood, or baled. If baled, either the bales will be measured in length and circumference and the volume calculated from the formula $v = s \times l$, or they will be weighed. The weight of bark will vary according to weather conditions and the length of time which has elapsed since felling and barking the trees; air dried bark loses 30% to 50% of its green weight.

4. Sawn Timber

The volume of *squared logs* and *scantlings*, the latter including *planks* and *boards*, is calculated from measurements of *length, breadth* and *depth*, the cubical contents being obtained from the formula

Volume in cubic feet =

$$\frac{\text{Breadth in inches} \times \text{Depth in inches}}{144} \times \text{Length in feet.}$$

A unit of measurement used in shipping squared and sawn timber is the *standard*. The *St. Petersburg Standard*, the one usually employed in the trade, = 165 cubic feet.

In retail trade scantlings in general are often sold by the running foot, and planks or boards by the superficial foot. The unit in the latter case is one *square* = 100 square feet, *e.g.*, 20 planks 10 ft. long × 6 ins. wide = 1 square. In America the volume of all timber is generally expressed in *board feet* (See p. 3).

1 board foot = 1 ft. broad × 1 in. thick × 1 in. long.

The unit employed for large quantities is M board feet = 1000 board feet.

B. MEASUREMENTS REQUIRED FOR STATISTICAL DATA

In addition to the measurements given above, the following may be required.*

1. Total Length of Stem

Definition.— The total length of a felled tree is the distance measured in a straight line from the tip to a point beyond the

* Special measurements required for determining increment are dealt with in Chapter VI.

actual butt of the tree, the addition being the allowance for stump height.

Objects of Measurement. — (i) As a check on the previous height measurement of the tree when standing (See Chapter IV), (ii) For the preparation of volume tables (See Chapter V), (iii) For determining form factor and form height (See next section), (iv) For stem analysis (See Chapter VI).

Procedure.— After removal of the intervening branches, measure in a straight line from the shaped portion of the butt to the tip of the tree and add the height of the stump. It is better to mark breast height on the tree before felling and to measure from this point to the tip of the tree, adding 4 ft. 3 ins. to the measurement obtained.

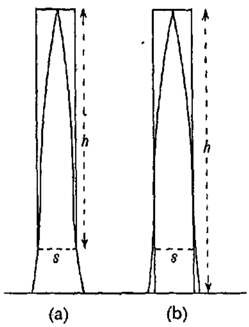


FIG. 8. The relationship between stem volume and cylindrical volume.

2. MEASUREMENTS REQUIRED TO DETERMINE FORM FACTOR (F.) AND FORM HEIGHT (F.H.)

Definition.— The form factor is the coefficient by which the volume of a cylinder, having the same length and cross-section as the tree, must be multiplied in order to obtain the volume of the tree (See *Fig.* 8). Three kinds of form factors are recognised, namely, *absolute form factors,* relating only to the portion of the tree above the point of measurement of the cross-section (See *Fig.* 8a); *true form factors,* relating to the volume for the whole length of the tree (*Fig.* 8b), where the point at which the cross-section is measured is a constant proportion, *e.g.* 1/10th, of the height of the tree above ground, and *artificial form factors,* as the latter, but the cross-section is measured at breast height.

Except in connection with form class measurements (p. 42) artificial form factors are the only ones now in use, and, unless

Objects of Measurement.—To obtain **conversion factors** by which stacked cubic feet may be converted into solid cubic feet, and thus all out-turn reduced to a common unit of measure and the total out-turn determined. Conversion factor $=\frac{\text{solid volume}}{\text{stacked volume}}$, usually expressed in decimals.

The following approximate conversion factors for good stacking have been worked out in Germany.

Pitwood and poles	0·75 to 0·80
Split fuel	0·75
Fuel faggots	0·6 to 0·7
Small branchwood (Conifers)	0·5
" " broad-leaved trees ...	0·35
Roots and stumps	0·5

If the wood is badly stacked the conversion factor may be much lower. It is probable that the standard cord 128 c. ft. was adopted with the idea that it represented 100 c. ft. solid, thus giving a standard conversion factor. Actually it does so under the most favourable conditions, *i.e.* 100=78% of 128. Chapman (8) states that the greatest content of a cord of stacked wood is about 105 c. ft. solid.

Procedures.— There are three methods, the Volumetric, the Xylometric and the Hydrostatic.

(i) *Volumetric Method.*—The solid volume of each billet is measured. (See Stem Wood Volume, p. 16). Since the billets will all be of the same length, the total solid volume will be calculated from the formula

$$V=S\times l$$

where S = sum of mean sectional-areas

l = length of a billet.

This method can, of course, only be applied where the billets are of very regular shape, *e.g.* pit props.

(ii) *Xylometric Method.*—A water container is required in which the wood can be submerged. The vessel either has a graduated scale on which the water level directly indicates the volume, or it has an overflow pipe from which the water overflows to a second graduated vessel. In the former case sufficient water is poured into the vessel to enable any piece of wood to be submerged, in the latter the vessel is filled to the overflow pipe. The wood having been submerged, the rise in level or overflow is noted. This reading gives the volume of the wood in question on the principle that a submerged body displaces its own volume. A saving in time is effected if the wood to be measured is first weighed; only a small portion need then be submerged; this will also be weighed and, as volume is in proportion to weight, the volume of the whole can be calculated from that of the portion submerged.

(iii) *Hydrostatic Method.*—The specific gravity of a substance is its weight in relation to an equal volume of water. The

weight of a cubic foot of water $=62{\cdot}5$ lbs. $\therefore$ the S.G. of a substance $=\dfrac{\text{weight of a cubic foot of the substance}}{62{\cdot}5 \text{ lbs.}}$

If the specific gravity of a substance is known, its volume can be obtained by weighing it. Thus, let the

specific gravity of a substance $=g$,
and its weight in lbs. $=W$,
and its volume in c. ft. $=V$,
then, since $g\times 62{\cdot}5=$ weight of 1 cubic foot of the substance,

$$\therefore W = \text{weight of} \frac{W}{g\times 62{\cdot}5} \text{ cubic feet of the substance.}$$

i.e. volume in cubic feet $=\dfrac{\text{weight in lbs.}}{g\times 62{\cdot}5}$ Formula 15.

To determine the specific gravity weigh the substance by means of a spring balance, first in air and then in water

Let $W=$ weight in air.
Let $W_1=$ weight in water.

The apparent loss in weight is due to the upward thrust of the water, and this loss must, by Archimedes' Principle, be equal to the weight of water displaced.

Thus the weight of a volume of water equal to V is $W-W_1$ and the specific gravity of the substance $=\dfrac{W}{W-W_1}$ and, substituting this value for g in Formula 15,

$$V=\frac{W}{62{\cdot}5}\times\frac{W-W_1}{W}=\frac{W-W_1}{62{\cdot}5}\text{ cubic feet.}$$

This is correct for a wood which sinks in water and has therefore a specific gravity of more than 1. Most species of wood, however, have a specific gravity less than 1, and therefore float. To such a sinker must be attached.

Using a Sinker.—Weigh the sinker in water, let its weight $=$ S lbs. W, g and V will have the same meanings as before, but $W_1=$ weight of wood + sinker in water.

Then, by definition, $W=g\times V\times 62{\cdot}5$ or $g\times V=\dfrac{W}{62{\cdot}5}$

If the wood is floating it will require a force of $V\,(1-g)\times 62{\cdot}5$ to depress it and the total downward pull registered on the spring balance will be $S-V\,(1-g)\times 62{\cdot}5$,

i.e. $W_1=S-V\,(1-g)\times 62{\cdot}5$.
$W_1=S-62{\cdot}5\,V+62{\cdot}5\,V\times g$.
i.e. $W_1=S-62{\cdot}5\,V\ +\ W$

and $V=\dfrac{W-W_1+S}{62{\cdot}5}$

If the value of g is required,

By definition we have $g=\frac{W}{V\times 62\cdot 5}=\frac{W}{62\cdot 5}\times\frac{62\cdot 5}{W-W_1+S}$

$$=\frac{W}{W-W_1+S}$$

NOTE.—*The volume and shape of the sinker are immaterial so long as its weight is sufficient to sink the wood.*

EXAMPLE.—A piece of wood which floats weighs in air 20 lbs. Attached to a sinker, having a weight in water of 5 lbs., the combined weight in water is 4 lbs.

then its volume $=\frac{20-4+5}{62\cdot 5}=0\cdot 336$ cubic feet.

and its specific gravity $=\frac{20}{20-4+5}=\cdot 952.$

CHAPTER IV

THE MEASUREMENT OF A STANDING TREE

Objects of Measurement.— The processes of management and sale frequently require that the merchantable volume or produce of a tree shall be determined before it is felled. Further, both management and research require certain measurements, which may or may not be directly concerned with the determination of volume.

A. ESTIMATE OF MERCHANTABLE VOLUME OR PRODUCE

Objects of Estimate. — For general management purposes the volume of individual trees is seldom required, and the total volume of a number of trees in any size class is obtained from volume tables (See next chapter), where these are available. For sale purposes, when trees are sold standing, volume tables are also sometimes used, but an individual estimate of each tree is more usual, and is almost universal in Great Britain.

Procedure.— Just as the volume of a log can be obtained from measurement of its length and diameter or girth at the middle, so the volume of a standing stem can be *estimated* from an estimate of these dimensions. For the purposes in question it is impracticable to measure girth or diameter at mid-height, but help in framing the estimate is obtained from the girth or diameter at breast height. There are no measurements which can be made on a standing tree which provide a reliable basis for estimating the quantity of crown or branch wood; though, in a specific forest, it may be possible roughly to correlate this quantity to the breast height dimension.

1. Diameter, Girth and Quarter-Girth at Breast Height

These are measured as for felled trees. Before measuring, moss creepers, etc., interfering with the contact of the tape or calliper with the tree must be removed.

In Great Britain a *timber strap* is sometimes used for sale purposes. It is a heavy leather strap graduated for quarter-girths with a hook at one end for fixing in the bark. It must be well stretched by hanging it up for several months in a wet condition with a heavy weight attached before being graduated.

2. Estimate of Stem Length

The stem is divided visually into a number of sections of a certain length. (See Chapter II.) Accurate estimate is assisted by placing a staff of known length against the tree and by the estimator always standing at the same distance from each tree estimated.

3. Estimate of Yield

The manner in which the estimate is made depends on the purpose for which it is required. An experienced estimator may estimate the volume of a standing tree, or even its yield in a certain class of converted timber, from a single measurement of its most easily determined dimension, *i.e.* d.b.h. or g.b.h. In Great Britain, when estimating for sale, it is customary to measure q.g.b.h., estimate stem length, with or without the help of a staff, and then to make a further estimate of mid-quarter-girth in order to obtain the volume from tables (Appendix II). Conifers are usually estimated in one length down to a minimum quarter-girth, which varies according to the purpose for which the timber is required, and the volume is sometimes calculated from the mean of the b.h. and top quarter-girths, to avoid estimating a mid-quarter-girth; thus

q.g.b.h. = 18 ins.
timber limit (arbitrary) = 6 ins.   mean = 12 ins.
Length (estimated) = 30 ft.

$$\text{Volume} = \frac{12 \times 12}{144} \times 30 = 30 \text{ cubic feet.}$$

In estimating broad leaved trees, where " stops " occur, the component logs are separately estimated, just as they are separately measured in felled trees. The measurements and estimates may be booked as shown for felled trees (p. 18), a column being added for q.g.b.h.

B. OTHER MEASUREMENTS REQUIRED FOR MANAGEMENT AND RESEARCH PURPOSES

1. Measurement of Girth or Diameter at Heights Other than Breast Height

Objects of Measurement. — (i) To calculate the volume of a standing tree in the same manner and as accurately as that of a felled tree (See Chapter III), (ii) Measurement of mid-girth or diameter to determine the form quotient or form class (p. 42).

Procedure.— Various suggestions have been made for measuring the tree from the ground, but in practice the only possible method is for a man to climb the tree, and for this pur-

pose a light ladder is usually used. Either the diameter or girth may be measured, but the latter is usually preferred owing to the difficulty of using a calliper in a restricted position.

2. Measurement of Diameter or Girth Under Bark

Objects of Measurement. — To determine the form quotient, or the volume of timber exclusive of bark.

Procedure.—The thickness of the bark may be determined with a Swedish *bark gauge.*

This instrument is in the form of a chisel, which is pushed into the bark. As the edge penetrates the bark a flange attached to the shaft slides back, and the extent of penetration, *i.e.* the thickness of the bark, is read off on the scale on the shaft. The instrument can be obtained from Messrs. Bens and Mattson, Mora, Sweden, graduated in 1/10ths of an inch for British purposes.

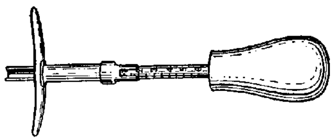


Fig. 9. Swedish bark gauge.

Double the bark thickness must be deducted from the d.o.b. measurement to obtain the diameter-under-bark (d.u.b.) measurement.

The girth-under-bark (g.u.b.) may be obtained from the girth-over-bark (g.o.b.) as follows.—

Let g=g.u.b., g'=g.o.b, r=radius u.b., r'=radius o.b., and t=bark thickness.

then $g = 2\pi r = 2\pi\ (r' - t)$

$$= 2\pi\left(\frac{g'}{2\pi}\right) - t$$

$$= 2\pi\frac{(g' - 2\pi t)}{2\pi}$$

$$= g' - 2\pi t = g' - 6{\cdot}28t. \qquad \underline{\text{Formula 16.}}$$

For quarter-girth measurement

$$qg = qg' - 1{\cdot}57t. \quad \underline{\text{Formula 17.}}$$

or, for each ¼ in. in thickness of bark, deduct 0·39 in. from the quarter-girth measurement over bark.

3. Measurement of Height

Definition. — The total height of a standing tree is the perpendicular distance from the tip of the leading shoot to the ground level (at the higher side of the tree on sloping ground). What is actually required in all cases is the length measured along the stem. The latter is, of course, only equal to the former if the tree is perpendicular. The difference, however, is small, and may be neglected in view of the much greater deviation from the true height, given by the usual methods of measurement in the case of a leaning tree (p. 40).

Objects of Measurements. — (i) where age is known, height for age gives a measure of the productivity of the locality

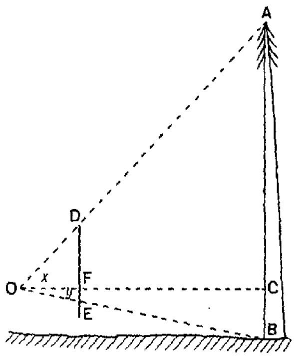


Fig. 10.

(See Yield Tables, Chapter VIII), (ii) the heights of selected trees in a wood may be required for the application of volume tables, form factor tables, and yield tables (See Chapters V and VIII), (iii) to determine increment by two or more measurements at intervals.

Theory of Height Measurement. — Methods of measuring the heights of standing trees are based on either geometrical or trigonometrical principles and they all assume that the tree is perpendicular. It is only possible to describe here a limited number of the many instruments which have been designed for measuring height, but a knowledge of the principles involved and the errors liable to occur will enable an operator to select the instrument most suitable for his purpose from those available.

In *Fig.* 10 AB is the tree to be measured, O the observer's eye, and DE part of the plumb line held so that the lines of observation OA and OB, to the top and foot of the tree respectively, cut the plumb line at D and E. DE being parallel to AB, by the laws of geometry DEO and ABO are similar triangles in which AB : OB : : DE : OE :

so that AB *i.e.* $H = \frac{DE \times OB}{OE}$ **Formula a.**

The values of the terms on the right hand side of this equation are obtained by measurement. With the distances at which the height of a tree is normally measured no appreciable inaccuracy is introduced by measuring OB from the observer's feet. Alternatively, if OFC be the horizontal line of observation cutting the plumb line at F and the tree at C, then the pairs of triangles DFO, ACO and FEO, CBO are similar and

$$H = AC + CB = \frac{DF \times OC}{OF} + \frac{FE \times OC}{OF}$$
$$= \frac{OC(DF + FE)}{OF} = \frac{DE \times OC}{OF} \quad \textbf{Formula b.}$$

so that in this case the horizontal distance of the observer from the tree, instead of his distance from the tree along the slope of the ground, is measured. If the point C is accessible, it may be more convenient to measure CB direct and to obtain only AC by calculation.

Applying trigonometrical principles* the angles of elevation and depression, x and y, to the top and foot of the tree respectively are measured, then

$$H = AC + CB = OC \tan x + OC \tan y$$
$$= OC (\tan x + \tan y) \quad \textbf{Formula c.}$$

As in the last case, if the point C is accessible, it will probably

* For those unacquainted with trigonometry the following note is given. In any right angled triangle ACO, as in *Fig.* 10,

$\frac{AC}{OC}$ is called the tangent (tan) of the $\angle$ AOC.

$\frac{AC}{OA}$,, ,, ,, sine (sin) of the $\angle$ AOC.

$\frac{OC}{OA}$,, ,, ,, cosine (cos) of the $\angle$ AOC.

For the same angle the above ratios are obviously the same whatever the size of the Δ, and the values for the angles in degrees are given in decimals in mathematical tables. Instead of being expressed in degrees the slope may be expressed as a per cent. Thus a 20% slope represents a rise of 20 units per hundred units in distance or the slope given by an angle whose tangent is $\frac{20}{100}$ *i.e.* 0·2, approximately 11½° (See Appendix VI).

be more convenient to measure CB direct and to apply the calculation only to the determination of AC. Likewise, it is obvious that, if the eye of the observer is on a level with the foot of the tree, the case is simplified and only one calculation is involved.

In practice the question will arise as to the accuracy with which it is possible to determine the horizontal distance OC, in view of the difficulty of holding the tape level. In this connection it may be pointed out that, even if the tape is held as much as 15% ($8\frac{1}{2}°$) out of the horizontal, the error in the distance and the consequent error in calculating the height will be in the neighbourhood of only 1%. It is generally true to say that,

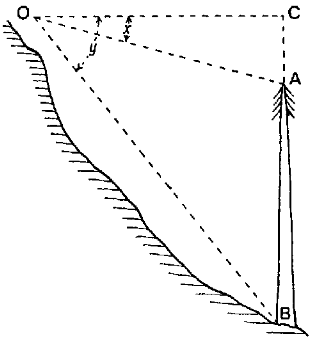


FIG. 11.

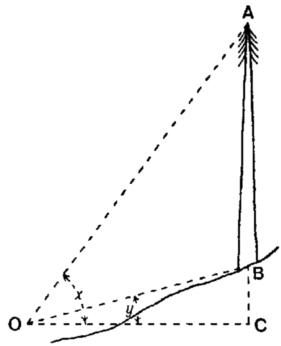


FIG. 12.

unless the slope exceeds 15%, the error arising from measuring along the slope to the foot of the tree (*i.e.* OB) instead of the horizontal distance (*i.e.* OC) is not important compared with the effect of other errors which will be dealt with later. The point is of some importance because calculations, and therefore instruments, are simplified if OC rather than OB is the basis of calculation. Using trigonometrical methods, the value of OC may be calculated from OB measured along the slope; thus

$$OC = OB \cos y$$

and from Formula c, $H = OB \times \cos y \times (\tan x + \tan y)$

Formula d.

A variation of this formula where $H = OB \dfrac{\sin (x+y)}{\cos x}$ (known sometimes as the law of sines) is the basis of some instruments.

Cases may arise in which the observer's eye is either above the top of the tree (*Fig.* 11) or below its foot (*Fig.* 12). (N.B.—

The latter is usually a very undesirable position to take up, as the difficulty—referred to later—of observing the true top and foot of the tree will be increased.) In neither case can OC be measured, and Formula d above will be modified as follows:—

Fig. 11. $H = OB \times \cos y \times (\tan y - \tan x)$ **Formula e.**

Fig. 12. $H = OB \times \cos y \times (\tan x - \tan y)$ **Formula f.**

Finally, by using a staff of known length, preferably with the feet marked in alternating colours, it is possible to avoid altogether the measurement of either OC or OB, a measurement which is sometimes impossible owing to the roughness of the ground between the observer and the tree.

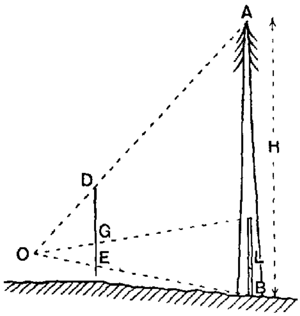


Fig. 13.

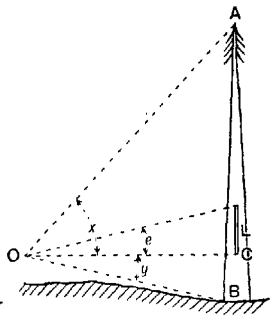


Fig. 14.

Thus, in *Fig.* 13, using the geometrical method with a staff of length " L " placed upright against the tree H : DE : : L : GE and $H = \frac{DE \times L}{GE}$ **Formula g.**

Using the trigonometrical method, if the horizontal line of sight cuts the tree within a few feet of the ground, as in *Fig.* 14, then the horizontal distance is very simply determined from a graduated staff. Thus, where " L " is the portion of the staff above the horizontal line, and " e " the angle of elevation to the top of the staff, then

$$OC = L \tan e,$$

and from Formula c.

$$H = L \tan e \ (\tan x + \tan y).$$ **Formula h.**

If the horizontal line of sight cuts the tree at a distance from the ground as in *Fig.* 15, then

$$L = CB - CT$$
$$= OC \tan y - OC \tan e$$
$$= OC (\tan y - \tan e)$$

and $OC = \frac{L}{\tan y - \tan e}$

and from Formula c, $H = \frac{L \quad (\tan x + \tan y)}{\tan y - \tan e}$ **Formula j.**

Procedures and Instruments. — Instruments used for measuring heights are known as *hypsometers;* those used to measure the angle of slope are known as *clinometers.* Any in-

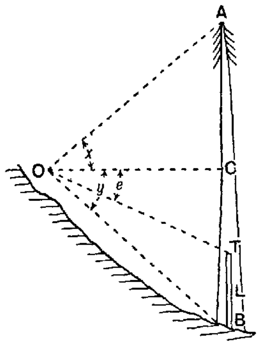


Fig. 15.

strument which will measure vertical angles can be used for measuring the heights of trees by trigonometrical methods, but some clinometers are especially designed for the purpose and may then be known as hypsometers. Trigonometrical hypsometers are usually designed with a scale which makes it unnecessary to use mathematical tables to determine the values of the tangents, etc., of angles. Before setting out to measure heights the ground should be studied in order that the method most suitable for the conditions may be adopted. Two operators are required to stretch the tape, one of them will observe the heights and the other will hold the graduated staff, if used, and be available to measure the portion of the tree below eye level. Whether or not the method adopted requires the measurement of

distances or the use of a graduated staff, it is desirable to carry both the measuring tape and the staff to meet unexpected circumstances. If, for example, the base of the tree is obscured by undergrowth, a staff placed against the tree will be required on which to sight. *The first essential in accurate measurement is for the observer to take up a position from which the true top and foot of the tree may be seen.*

The following are a few examples of the instruments which may be used.

(a) *Instruments based on geometrical principles. — Single Pole Method or Staff Hypsometer.* (*Fig.* 16.) Hold a staff, about 5 ft. long and weighted at the bottom, at arms length at E so that the distance (DE) of the hand below the top of the staff = the distance from the eye to the staff (OE). Move back-

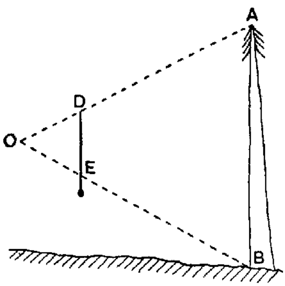


FIG. 16. Staff hypsometer.

wards and forwards until the line of sight ODA falls on the top of the tree and the line of sight OEB at its foot. The distance of the observer from the tree will then give its height. This is so because DEO and ABO are similar triangles and, since DE = OE, ∴ AB = OB. The staff must be held perpendicular; it should, therefore, be held loosely, and the part below the hand should be heavier than the part above. The distance from the hand to the eye must be kept constant, therefore the head must not be moved when stepping backwards and forwards to find the correct position. This method is suitable for use on easy ground where no better instrument is available.

Christen's Hypsometer.—This instrument consists of a strip of metal or wood with projecting upper and lower edges (*Fig.* 17). It is used with, and graduated for, a staff of known length, and has therefore the advantage that the distance from the observer to the tree need not be measured. To obtain the height

of the tree, the staff BC is placed in an upright position against the trunk of the tree and the observer stands at a distance and holds the instrument from the top so that it hangs vertically like a pendulum. He then moves it backwards and forwards in front of his eye until the lines of sight through the lower edge of the upper projection and the upper edge of the lower projection respectively cut the top and base of the tree. The point where the line of sight to the top of the staff cuts the scale on the instrument will give the total height of the tree in the same units as the staff is graduated for. The following instructions

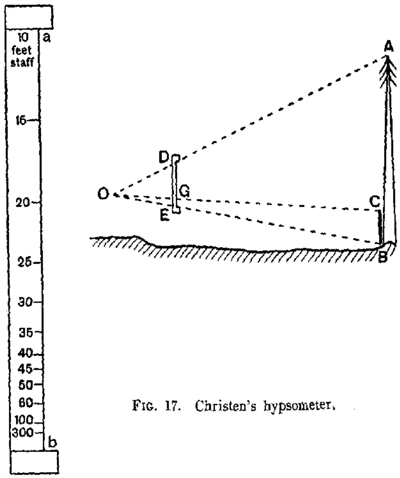


FIG. 17. Christen's hypsometer.

for graduating the instrument will explain why this is so:—Any unit, a staff of any length and an instrument of any length may be used. Most commonly a 10 ft. staff is used with a 15 in. instrument, *i.e.* 15 ins. from "a" to "b" (*Fig.* 17), "a" being the point of origin of the scale and marked 10 ft. It is clear that similar triangles are formed in which AB : DE : : AC : DG

$$DG = \frac{DE \times AC}{AB}$$

Thus, for a tree 40 ft. high $DG = \frac{15 \times 30}{40} = 11{\cdot}25$, so that the

40 ft. division on the scale will be marked at 11·25 ins. from " a " and similarly for other heights. As the rules of proportion hold good a staff of different length to that for which the instrument is made may be used, *e.g.* if a 5 ft. staff is used the heights obtained will be divided by two.

On the 15 in. instrument heights above 40 ft. cannot easily be read to the nearest foot, and above 100 ft. the divisions are so close that the instrument is of little value. A longer instrument is sometimes made, hinged in the middle so as to fold when out of use. The instrument is particularly useful on rough ground where distances cannot be measured.

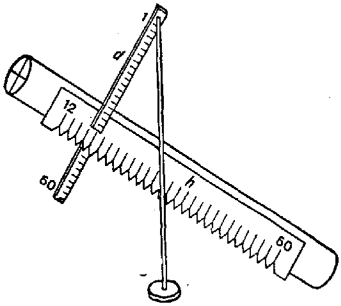


Fig. 18. Weise's hypsometer.

Weise's Hypsometer. (*Fig.* 18.)—Consists of a tube with an objective in the shape of a cross at one end and an eye-piece at the other. The height scale " h," notched along its outer edge, is fastened along the upper side of the tube; it has the zero point some distance from the end and is graduated in both directions. A second scale " d," known as the distance scale, is inserted at the zero point of the height scale and moves at right angles to it. From the upper, or zero point, of this scale is suspended a plumb rod with a sharp inner edge. Both scales are graduated in units of the same dimension. In using the instrument (*Fig.* 19) the horizontal distance from the point of observation to the tree is measured, and the distance scale is set at the equivalent number of units. The instrument is then directed to the top of the tree, inclined slightly to the left so that the plumb rod is free. With the intersection of the cross lines of the objective held on the tip of the tree, the instrument is turned gently to the right so that the edge of the plumb rod is caught in a notch of the height scale. The reading opposite this notch then gives the height of the tree above the eye in the units chosen.

The height of the tree below the eye is determined in a similar manner by directing the instrument on the foot of the tree.

EXAMPLE :

Observer stands at 20 yards from the tree.
Set " d " scale at 20; direct instrument on top of tree.
" h " scale reads $16 = 16^{x} = 48'$.
Direct instrument on foot of tree.
" h " scale reads $2 = 2^{x} = 6'$.
Height of tree $= 48 + 6 = 54$ feet.

The theory of the instrument rests on the similarity of the triangles RHD and rhd

$$H : D :: h : d \text{ and } H = D \times \frac{h}{d}$$

Since a unit of the " h " scale = a unit of the " d " scale, and,

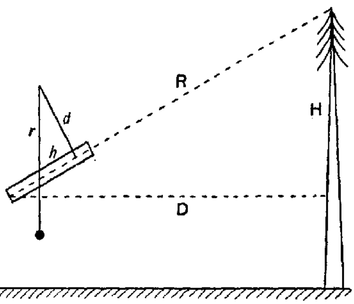


FIG. 19. Use of Weise's hypsometer.

since the number of units in d = number of units in D, it is clear that, whatever measurement units be chosen, " H " will contain the same number of them as are indicated by the " h " scale on the instrument.

Should the level of the observer's eye be below the level of the foot of the tree then it is clear that, since the first reading gives the height of the top of the tree and the second that of the foot of the tree both above the observer's eye, the second reading must be deducted from the first to obtain the height of the tree. Since it is the horizontal distance which has to be measured the instrument is unsuitable for use up or down a steep slope, ~~though by measuring to the top of a staff of known length placed against the tree this difficulty may often be got over~~.

(b) *Instruments based on trigonometrical principles.*—These instruments are more expensive, but give more accurate results

than those based on geometrical principles and are more useful on steep slopes and difficult ground. They measure the angles of elevation and/or depression from the observer to the top and foot of the tree. Many convenient hand instruments of different design are on the market. Three types may be considered, differing in the manner in which their scales are constructed.

Type 1.—The scale shows the angle in degrees and a table accompanies the instrument giving the heights for various angles and distances. These instruments are generally based on Formula d (p. 32), the distance referred to being that along the ground and not horizontal, so that their use is not confined to moderate gradients, *e.g.* Brandis's and Smythie's hypsometers.

Type 2.—In addition to degrees, the scale shows inches in height per yard of distance of the observer from the tree. Thus, in *Fig*. 10,

OC=20 yards, and, for the angles x and y, the scale reads respectively 33 and 3, then

$$AC = \frac{33 \times 20}{12} \text{ feet} = 55 \text{ feet},$$

$$CB = \frac{3 \times 20}{12} \text{ feet} = 5 \text{ feet},$$

and H=60 feet;

or using a staff as in *Fig*. 14, p. 33, where L=5 feet, and, for the angle e, the scale reads 3, then

the horizontal distance $OC = \frac{5 \times 12}{3} = 20$ yards.

Then, observing again to the top and foot of the tree, its height is calculated as before.

Used as above the instrument requires the measurement of either the horizontal distance of the observer from the tree or of the height of a point above his eye. It cannot, therefore, be used in the manner described, either with or without a staff, on steep up or down gradients, *i.e.* in the conditions illustrated in *Figs*. 11, 12, and 15, pp. 32 & 34, though, in such cases, by reading in degrees and using mathematical tables, the height may be calculated by Formulæ e, f or j.

Type 3.—The scale shows the percentage of slope, that is the rise or fall in height per 100 units of distance (horizontal). The reading, therefore, gives directly the value of tan x or y (*Fig*. 10, p. 30).

Thus, if the angle x represents an 80% and the angle y a 10% slope, and the distance is 60 feet,

$$\text{then } AC = \frac{80}{100} \times 60 = 48 \text{ feet},$$

$$\text{and } CB = \frac{10}{100} \times 60 = 6 \text{ feet},$$

and H=54 feet.

There is an Abney's level on the market constructed in this

manner. The instrument has the same limitations as the last type.*

Principal Sources of Error. — Apart from errors in the instrument used and those due to the personal factor, errors are due to mistakes either in measurement or observation, or to leaning trees.

(a) *Measurement.* — The error in measuring the horizontal distance owing to not holding the tape level, or in the calculation owing to the substitution of the distance along the ground for the horizontal distance has already been dealt with (p. 32). The error in calculating the height due to an incorrect measurement of the angle will be least if the distance from the observer of the tree is the same as the height of the tree. Consequently, old writers on mensuration recommended the general adoption of such a position. This is a mistake based on a failure to appreciate all the errors which are likely to occur and their varying importance in calculating the height. Errors arising from incorrect observation and measuring leaning trees, on the assumption that they are perpendicular, are more serious than those arising from wrong measurement.

(b) *Observation.* — Owing to the position taken up or to undergrowth, the true foot of the tree may not be observed. If the foot is obscured the difficulty may be got over by observing a staff placed upright against the trunk. Owing to the shape of the tree it may be difficult to see the top. The greater the distance from the tree the easier to see the top. The effect, on the calculation of the height of the tree, in observing the tip of a branch which is not the true top is the same as that produced by measuring a tree leaning towards the observer, and is dealt with below.

(c) *Leaning Trees.*—It may be possible to avoid measuring noticeably leaning trees; but the departure from the perpendicular may be imperceptible, yet at the same time sufficient to result in a considerable error in the calculation of the height if the tree is measured on the assumption that it is perpendicular. Chaturvedi (2) has shown that the error may be reduced by increasing the distance of the observer from the tree beyond the point, where distance = height and angle of elevation = 45°—see (a) above. Chaturvedi's table of deviations and errors for trees leaning towards and away from the observer is reproduced below.

* The usual type of Abney's level has the proportionate heights for distances for slopes from 1 in 1 to 1 in 10 marked on the scale and can therefore be used under some conditions directly as a hypsometer; but, unless a position is selected so that the gradient corresponds with one of the few marked on the scale, its use is likely to result in inaccuracies.

Deviation from the vertical	Angle of observation to the top of the tree: 45° Towards	45° Away	60° Towards	60° Away	30° Towards	30° Away
5°	+ 8%	− 9%	+15%	−15%	+ 5%	− 5%
10°	+16%	−19%	+29%	−32%	+ 8%	−12%
15°	+22%	−29%	+41%	−48%	+11%	−19%
20°	+28%	−40%	+53%	−65%	+13%	−26%

Thus, if a tree has a lean of 5° from the perpendicular towards the observer, the error from calculating its height, as though it were perpendicular, will be +8%, +15%, or +5% according to whether the angle of elevation to the top of the tree is 45°, 60°, or 30°. It will be observed that the errors for trees leaning away from the observer are greater and negative. The table shows that more accurate measurements are to be expected the further away, within reason (*i.e.* taking into consideration the length of line to be measured), the observer is from the tree.

4. Measurement of the Stem Volume

Definition.— The stem volume of a standing tree is the volume obtained by the standard method of measurement after the tree is felled. The accuracy of any method of measuring the volume of a standing tree is therefore judged by the nearness with which the result approaches this measurement.

Objects of Measurement.— The volume of a sample plot (See Chapter VII) is estimated from the measured volumes of sample trees. It is not always convenient to fell such trees and foresters have, therefore, sought to devise methods by which they can be accurately measured.

Procedures.— (a) *By Direct Measurement.*—A man climbs the tree by means of a ladder and makes the necessary length, and diameter or girth measurements for calculating its volume, in the same way as for felled trees.

With *Bühler's* ladder as used in Switzerland trees of 25 metres in height may be measured (4).

(b) *By Form Factors.*—Form factors vary within comparatively narrow limits, and it may be possible to estimate the form factor with sufficient accuracy to determine the volume of the tree from Formula 12 (p. 22).

$$V = s \times h \times f.$$

(c) *By Form-class Taper Tables.* — Form-class taper tables are based on the theory expounded by Metzger (p. 9) that the taper of trees is not fortuitous, but results from certain factors in the environment which compel the tree to construct a bole in which there are definite diameter relationships in different parts of its length. Granted that this is so, it would appear that. by connecting up these relationships with some measurable dimen-

sion, it should be possible to arrive at a method which will overcome the inherent difficulty in accurately measuring the volume of a standing tree. Coniferous trees, with their simpler structure and more regular growth than broad leaved trees, presented the most promising material for investigation, and so far research has been confined to them. An Austrian investigator, A. Schiffel, first showed in 1905 that taper depended on the **form quotient** (f.q.) which he defined as *the ratio between the mid-diameter and the d.b.h.*, thus

$$\text{f.q.} = \frac{\text{mid-diameter}}{\text{d.b.h.}}$$

Tor Jönson, a Swedish forester, showed that this was not an absolute ratio and re-defined the form quotient as the ratio between the mid-diameter *above* breast height and d.b.h.; this he called the *absolute form quotient.* It is the latter which is now generally understood by the term form quotient. It is clear that the effect of the varying proportion of breast height to total height, in trees of different total heights, is eliminated to some extent by Tor Jönson's definition. By Schiffels' definition a tree 8 ft. 6 ins. in height would necessarily have a form quotient of 1—since the points of measurement coincide—though its taper might be the same as that of a tree say 18 ft. 6 ins. in height with a form quotient less than 1.

Example of determining the form quotient by Jonson's method.

Total height 60 ft.

diameter at $\frac{60\text{ ft.} - 4\text{ ft. } 3\text{ ins}}{2} + 4\text{ ft. } 3\text{ ins.}$ (equiv. to $\frac{60\text{ ft.} + 4\text{ ft. } 3\text{ ins.}}{2}$)

i.e. at 32 ft. $1\frac{1}{2}$ins. above ground = 10 ins.

d.b.h. = 18 ins.

$$\text{f.q.} = \frac{10}{18} = 0{\cdot}56.$$

Kunze, a German, confirmed the fact that taper is related to the form quotient by showing that

$$\text{f.q.} - \text{c} = \text{form factor}$$

where c is a constant for the species, thus also providing a means of determining the form factor if c is known.

In order to represent the taper of a tree independently of its length, measurement is made at positions representing 10%, 20%, 30%, etc., of the distance between b.h. and the tip of the tree. The ratio of the diameter or girth at any level to d.b.h. or g.b.h. is known as the *diameter* or *girth quotient.* These quotients are represented in decimals, and trees, having the same form quotient, are said to belong to the same **form class.** A *form-class taper table* is a table which gives for any form class the diameter or girth quotients for positions representing fixed percentages of the distance between breast height and the tip of the

tree. Metzger's theory relates to the taper of a tree underbark. The taper over bark may or may not be the same. Where the bark is thin the difference will be unimportant. Jönson found that for thin barked Norway Spruce the taper over bark was essentially the same as the taper under bark. In the case of thick barked species investigations must be made to determine whether or not the bark thickness has a constant ratio to the diameter throughout the length of the stem, and, if it has not, it must be determined at the levels where measurements are made and the under bark dimensions used.

Tor Jönson drew up the first taper tables for Norway Spruce, using a formula devised by Höjer, a Swedish engineer, to determine diameter quotients for each form class.

Höjer's formula $\frac{d}{D.B.H.} = C \log \frac{c+l}{c}$

where d = diameter at any point on the stem.
C and c are constants for each form class.
and l = distance from the top of the tree to the point at which "d" is measured, its value being given as a percentage of the length of the tree between b.h. and the top.

The validity of the formula was tested on a large number of felled trees.

An American investigator, C. E. Behre (6) carried out similar investigations in the U.S.A., and evolved the following formula, which is simpler than Höjer's and appears to be more applicable to the British and American conifers.

Behre's formula $\frac{d}{D.B.H.} = \frac{l}{a+bl}$

where a and b are constants for each form class, a+b=1, and the other terms have the same meaning as in Höjer's formula.

The following is an extract from Behre's taper tables.

Form Class	Diameter as a percentage of d.b.h at								
	10	20	30	40	50	60	70	80	90
	per cent. of the stem above breast height								
60·0	93·10	85·72	77·78	69·23	60·00	50·00	39·13	27·27	14·29
65·0	94·36	88·13	81·24	73·58	65·00	55·32	44·31	31·71	17·11
70·0	95·45	90·32	84·48	77·78	70·00	60·86	50·00	36·84	20·59
75·0	96·43	92·30	87·50	81·82	75·00	66·67	56·25	42·85	25·00
80·0	97·30	94·12	90·32	85·71	80·00	72·73	63·16	50·00	30·77

The procedure in preparing the table is briefly as follows: Calculate the values of the constants a and b by substituting values for the variables which are fixed for any form class by definition of form quotient.
Thus, for form class 75 we have

$$\left.\begin{array}{l} \cdot 75 = \dfrac{\cdot 50}{a+\cdot 50b} \\ a+b=1 \end{array}\right\} \quad \text{or} \quad \left\{\begin{array}{l} \cdot 75a+\cdot 375b=\cdot 50 \\ \cdot 75a+\cdot 75b=\cdot 75 \end{array}\right.$$

By subtraction $\cdot 375b = \cdot 25$

$b = \cdot 667$

and $a = 1 - \cdot 667 = \cdot 333$

Hence at 10% above b.h. (90% from the top)

$$\text{diameter quotient} = \frac{\cdot 90}{\cdot 333 + \cdot 667 \times \cdot 90} = \cdot 9643$$

and diameter required = 96·43% of d.b.h.

The method of using the taper table to determine the volume of a tree is shown in the following example.

EXAMPLE:

Total ht. = 64 ft. 3 ins.

Ht. above b.h. = 60 ft., of which 10% = 6 ft.

d.b.h.u.b. = 8 ins.

d.u.b. at $\frac{64 \text{ ft. } 3 \text{ ins.} + 4 \text{ ft. } 3 \text{ ins.}}{2}$

i.e. at 34 ft. 3 ins. = 5·6 ins.

Form quotient $= \frac{5 \cdot 6}{8} = \cdot 70.$

From the above table for form class 70 we find that, where d.b.h. = 8 ins.

d. at 10% above b.h., *i.e.* at 10 ft. 3 ins. (4 ft. 3 ins. + 6 ft.) = 95·45% of 8 ins. = 7·6 ins.

d. at 20% above b.h., *i.e.* at 16 ft. 3 ins. = 90·32% of 8 ins. = 7·2 ins., etc., etc.

Draw a diameter-height curve from the above data.* Divide the stem into sections of convenient length and determine from the graph the mid-diameters of the several sections, in order to obtain their volumes.

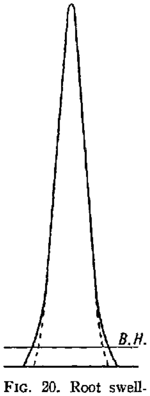


FIG. 20. Root swelling. Broken line = normal stem form.

It will be observed that, before the table can be applied, a measurement has to be made, to determine the form class, at a level involving the use of a ladder. This cannot be got over where the volume of a *single tree* has to be accurately determined. Other methods of determining the form class, which eliminate this measurement, are employed; but, since they depend on average data, they are only suitable for determining the mean volume of a number of trees in the same class, and are therefore dealt with under volume tables in the next chapter.

In Great Britain James Macdonald, working on behalf of the B.F.C. (5, 4 & 3), has found that Behrer's curves give generally correct results for the middle portion of the stems of British conifers, but are less accurate for the top and butt logs. He says, "Errors near the top do not as a rule affect measurement, as they generally apply only to the portion above timber limit. The departure of the butt log from the normal curve is due to the feature known as root swelling (See Chapter II). Butt logs can be measured directly, but, if root swelling extends up to breast height, then the form quotient is affected, the wrong curve may be applied and the volume wrongly calculated" (*Fig.* 20).

In order to eliminate the error due to root swelling Dr. Anderson modified the above method of measuring an individual tree in the following manner. The method is used by the B.F.C.

* See Appendix VII.

in measuring sample trees in coniferous sample plots. It will be observed in the example given below that the taper of the lower part of the stem is obtained by direct measurement.

EXAMPLE:

Measurement of a sample tree 64¼ ft. high; up to about 35 ft. is accessible with a ladder.

64¼ ft. − 4 ft. 3 ins. = 60 ft., 10% of which = 6 ft.,

therefore girths are required at 4 ft. 3 ins., 10 ft. 3 ins., 16 ft. 3 ins., 22 ft. 3 ins., 28 ft. 3 ins., 34 ft. 3 ins., 40 ft. 3 ins., 46 ft. 3 ins., 52 ft. 3 ins., and 58 ft. 3 ins.

The first two columns of the following table are filled in from measurements made by a man going up the tree with a ladder, and girth quotients in column 3 calculated from $\frac{g}{\text{g.b.h.}}$

Height in feet	Girth in inches u.b.	$\frac{\text{Girth}}{\text{g.b.h.}}$ = girth quotient	Girth quotients after elimination of root swelling
4 ft. 3 ins.	28¼		
10 ft. 3 ins.	25½	0·902	0·977
16 ft. 3 ins.	24½	0·868	0·930
22 ft. 3 ins.	23	0·814	0·872
28 ft. 3 ins.	20¾	0·735	0·788
34 ft. 3 ins.	19	0·673	0·721 (form quotient)

The heights in column 1 of the table are next plotted as ordinates over the girth quotients as abscissæ (See *Fig.* 21). A smooth curve drawn

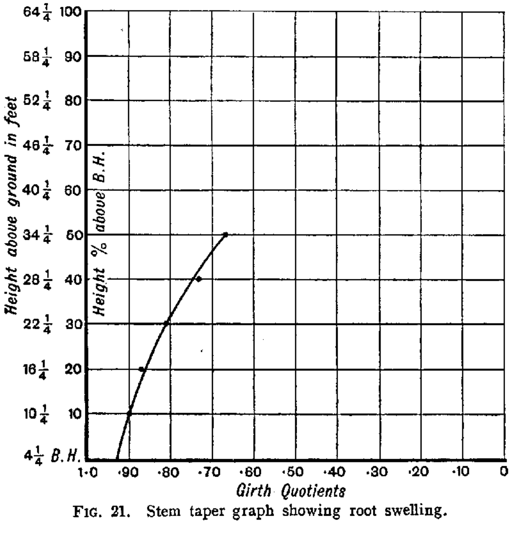


FIG. 21. Stem taper graph showing root swelling.

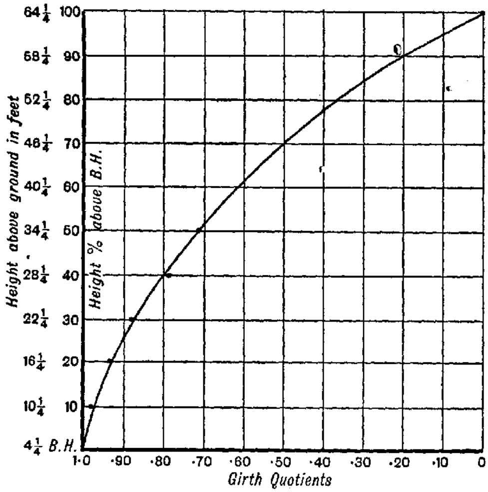


FIG. 22. Normal stem taper graph showing root swelling eliminated.

through these points does not pass through the point of origin of the curve at breast height, thus indicating that the effect of root swelling extends beyond breast height and that 0·673 is not the true form quotient. Actually the curve cuts the abscissa at 0·933 from the point of origin, showing that

$$\frac{\text{Normal g.b.h.}}{\text{Actual g.b.h.}} = 0.933$$

and normal g.b.h. $= \text{actual g.b.h.} \times 0{\cdot}933$
$= 28\frac{1}{4} \times 0{\cdot}933$
$= 26{\cdot}36$ ins.

Using this new normal g.b.h. as divisor, the girth quotients are recalculated and column 4 of the above table filled in, showing that the true form quotient is 0·721.

The graph is now redrawn (See *Fig.* 22), using the figures in column 4 of the table. For that portion of the curve which lies above the 50 height percentage, Behre's curve for the 72 form class is used. (0·72 being the form quotient.)*

The volume of the tree is now determined as follows:—The tree is divided into the usual 10 ft. sections and the mid-girth of each section, *i.e.* at 5 ft., 15 ft., 25 ft., etc., determined, for the lower part of the stem from actual measurements, and at other points from *Fig.* 22. Following

* In this example the form class has been determined from the *measurement* at 50% above breast height. If this point cannot be reached with a ladder, the curve (*Fig.* 22) is drawn as far as the measured points allow and then continued tentatively to the 50% point in order to see to which of the form classes the tree belongs.

along the 45 foot line, for example, we find the girth quotient$=0{\cdot}533$, so that the girth at this point$=26{\cdot}36\times0{\cdot}533=14{\cdot}05$ ins., and the quarter-girth volume $=\left(\frac{14{\cdot}05}{4}\right)^2\times\frac{1}{144}\times10$ cubic feet, similarly for other sections which were not directly measured. The number of sections into which the stem is divided for measurement purposes will be determined by the timber height. This is, by definition, where the stem is 9 ins. in girth under bark; the girth quotient at this point is $\frac{9{\cdot}0}{26{\cdot}36}=0{\cdot}341$.

From the graph it is seen that this point lies at about 54 feet above ground, so that it will be convenient to divide the stem into four 10 ft. and two 7 ft. sections.

The above method is used by the B.F.C. in measuring sample trees in coniferous sample plots.

CHAPTER V

VOLUME TABLES

A. OBJECTS

In the last two chapters attention has been directed to the measurement of individual trees, and it has been shown how the volume of such may be determined with some degree of accuracy. For general management purposes the forester is more often concerned with the total volume of a large number of trees and, therefore, a knowledge of the average volume of a tree falling within certain dimensions—those being chosen which can be easily measured—is all that is required. Until recently volume tables have been based on the breast height dimension and/or total height; volume tables based on form are now being brought into use. A **volume table** may, therefore, be defined as a statement giving in tabular form the average volumes of trees by girth diameter, height or form classes. They are used for determining the volumes of both felled and standing trees.

B. SCOPE OF TABLES AND CHOICE OF VARIABLE

The tables may be *Local, Regional* or *General* according to whether they are applicable to one forest only, a number of forests in one locality, or in the forests covering a large geographical area. The choice of the variable or variables on which to base the tables depends to some degree on the extent of their intended application.

The factors which determine the volume of a tree are diameter (or girth), height, and form. The considerations which govern the choice of the variable or variables, on which the tables are based, are simplicity and speed in their application—particalarly to standing trees—and accuracy. The first requirement is best served by basing the tables on the breast height dimension only (See table on p. 50); but such tables will also be the least accurate, in that they assume that trees of the same b.h. dimension have the same *average* height and form. The variables are not, however, entirely independent of one another, in that they all depend on certain factors, such as age, site qualities, and the general conditions affecting growth. Thus, if a set of tables is

prepared for and applied to strictly limited conditions, *i.e.* sites which have the same ecological and productive value and trees grown under the same silvicultural system, they may be quite sufficiently accurate, even though based on only one variable. If all the variables could be determined by simple measurement, a table based on all three variables would be much more accurate and would be of much more general application than one based on one variable only; in fact it could even be used for different species if the same formula were found to apply to the taper of these species. In practice, however, variables other than diameter or girth generally have to be estimated. An estimate of height is likely to be sufficiently correct to result in tables, based on diameter and height (See p. 52), being more accurate than those based on diameter only, and general tables are usually so prepared. The peculiar difficulties which arise in estimating form class are dealt with later under form class volume tables. These difficulties are likely to prevent an extended use of such tables directly for forest work, though they may provide data useful for the preparation of local tables based on diameter and height. To the author it appears that the older types of volume tables provide all that is required for the general purposes of forest management, that is to say that, when used for large numbers of trees, they result in figures which agree sufficiently closely with the measured volume of the trees when felled.

C. VOLUME TABLES BASED ON A SINGLE VARIABLE

Preparation.— The data for volume tables are obtained by felling a large number of trees and measuring their volumes. The trees felled over a number of years for sale may be used for this purpose. The breast height measurement is first taken, and the tree is then felled and measured up—preferably in sections—as explained in Chapter III. The data is then tabulated as shown in the table on the next page.

Data collected for volume tables for *Pinus longifolia* in the Rawalpindi District. Soil Quality I.* Stem wood and bark down to 6 ins. g.o.b.

No.	g.b.h. ft. ins.	Volume c. ft.	No.	g.b.h. ft. ins.	Volume c. ft.	No.	g.b.h. ft. ins.	Volume c. ft.
1	2 1	8	24	4 2	52	47	5 2	122
2	2 2	10	25	4 3	70	48	5 8	128
3	2 2	10	26	4 4	54	49	5 9	128
4	2 3	12	27	4 5	78	50	5 9	148
5	2 3	16	28	4 6	76	51	5 10	156
6	2 3	12	29	4 6	80	52	5 10	126
7	2 4	14	30	4 7	86	53	5 10	156
8	2 6	14	31	4 9	82	54	5 11	102
9	2 10	24	32	4 10	100	55	6 0	136
10	2 10	24	33	4 10	84	56	6 0	110
11	2 10	20	34	4 11	88	57	6 0	98
12	2 11	24	35	5 0	84	58	6 2	162
13	3 1	26	36	5 0	104	59	6 2	116
14	3 2	30	37	5 0	56	60	6 3	162
15	3 4	38	38	5 2	88	61	6 4	154
16	3 7	40	39	5 2	84	62	6 4	148
17	3 7	42	40	5 3	90	63	6 4	130
18	3 9	78	41	5 4	122	64	6 4	118
19	4 0	44	42	5 5	92	65	6 5	150
20	4 1	60	43	5 6	124	66	6 5	154
21	4 1	60	44	5 6	110	67	6 6	134
22	4 1	52	45	5 6	66	68	6 6	140
23	4 2	68	46	5 7	124	69	6 6	178

It is desired in this case to prepare a table showing volumes by 6 in. girth classes. The data are transferred to a graph (*Fig.* 23)† and the volume table is prepared from the graph as shown below.

TABLE I

Regional Volume Table

Rawalpindi, Pinus longifolia. Locality Quality I.

Volume in the round down to 6 in. g.o.b.

Girth Class	Volume c. ft.
2 3	14
2 9	22
3 3	33
3 9	48
4 3	64
4 9	81
5 3	99
5 9	119
6 3	142

* Separate tables are prepared for each quality of locality. Since height for age is a measure of quality, and g.b.h. also depends largely on age, the height variable may be said to be taken into account in the tables. Moreover, since the forests are open and there is not much competition, particularly in the larger classes, the assumption that height and form are in proportion to girth is probably fairly correct.

† See Appendix VII: the use of graphs.

Principal Sources of Error.—(See Appendix VII). (i) Failure to measure sufficient trees. (ii) Failure to draw an average curve through the plotted points. (iii) Use of an unsuitable scale on the graph.

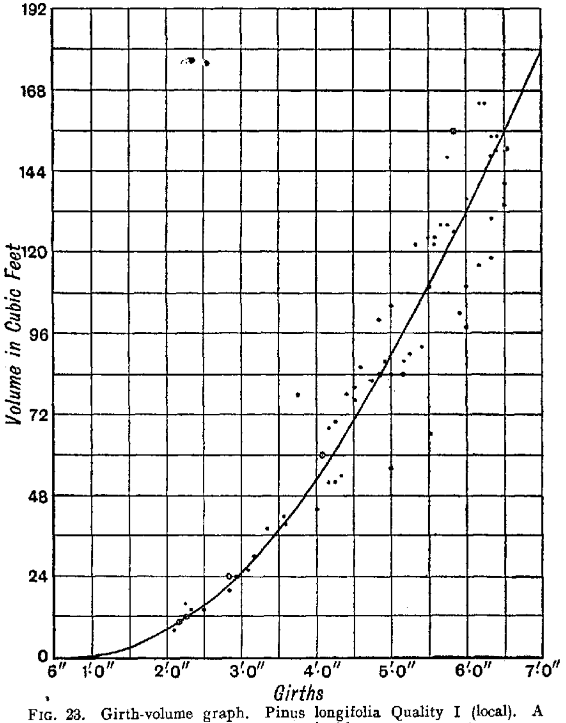


FIG. 23. Girth-volume graph. Pinus longifolia Quality I (local). A ringed point indicates two coincident measurements.

Application.— The g.b.h. of each tree is measured to determine the girth class, and the total number of trees in each class multiplied by the corresponding volume in the table. The tables may be used for (i) the purpose of estimating the volume of the growing stock (wood capital) to serve as a basis for the organisation of management, (ii) estimating the volume of standing trees

before felling with the object of regulating the yield in accordance with working plan prescriptions.

Table I was required for trees enumerated in 6 in. girth classes from the 2 ft. 0 in. – 2 ft. 6 in. class upwards; but the graph could be used for the preparation of a table of any girth class required. A volume table of this nature is not suitable for determining the average volume of a very small number of trees in one girth-class, nor should *general* volume tables be based on only one variable.

D. VOLUME TABLES BASED ON TWO VARIABLES

Preparation.— With the following exceptions the procedure is the same as that just described. In addition to girth (or diameter) and volume, the total height of the felled trees is recorded in height classes, usually with limits of 10 or 5 feet. Separate graphs are prepared for each height class. The volume table is prepared as shown in the following example.

TABLE II

General Volume Table

Extract from British Volume Table for Larch.

G.B.H. Class inches	Height in feet. 30–40	40–50	50–60	60–70	70–80	80–90	90–100
	Volume per tree, cubic feet (under bark)						
8	0·06						
12	0·64	0·66	0·74				
16	1·40	1·58	1·80	3·10			
20	2·40	2·78	3·25	3·7	4·2		
24	3·66	4·20	4·90	5·8	6·7	7·6	
28		5·8	6·8	8·2	9·6	10·8	12·2
32		7·7	9·1	11·0	13·0	14·5	16·0

Principal Sources of Error. — These are the same as for the last method, but the introduction of a second variable makes the tables more accurate when applied to a small number of trees. Since in application the height class is usually estimated, an additional source of error is introduced; but this should not be serious if the height classes are not made too small.

Application.— General volume tables may be prepared by this method. The tables may be used in any locality covered by the tables for (1) Estimating the volume of the growing stock (wood capital) to serve as a basis for the organisation of management. (2) Estimating the volume of standing trees before felling for the purpose of regulating the yield in accordance with working plan prescriptions. (3) Estimating the volume for sale purposes or regulating the yield according to saw mill requirements. In tables prepared for this purpose stem-length is often sub-

stituted for total height, giving *stem-length* volume tables: the limits of stem-length classes would generally not exceed 5 ft. and might be less.

When applying the tables the d.b.h. or g.b.h. is usually measured and the height estimated. To avoid estimating heights, local volume tables, based on one variable, may be prepared from a general table by preparing a d.b.h. or g.b.h. height curve from data collected locally. Thus, if the following information be available from the local height curve

g.b.h. class in inches	Average height in feet	g.b h. class in inches	Average height in feet
8	33	24	62
12	38	28	68
16	46	32	75
20	55		

then the local volume table, based on Table II, will be

TABLE III

g.b.h. class	Volume
8	0·06
12	0·64
16	1·58
20	3·25
24	5·8
28	8·2
32	13·0

An alternative method of drawing up these tables is to give the form factors instead of volume. The form factors having been obtained for a sufficient number of felled trees (See Chapter III) the results are graphed and average form factors obtained as for volumes in volume tables. The same form factor will apply to considerable variations in diameter and height and consequently the tables may be abbreviated. Their use involves calculations from the formula $v = s \times h \times f$ for each class. If the volume of a few trees is required, and, if it is possible to measure the heights of a considerable proportion of them, the results are likely to be much more accurate than those obtained from the usual volume tables.

E. FORM-CLASS VOLUME TABLES

Preparation.— The tables are based on theoretical taper tables (p. 43). The latter apply to u.b. dimensions, whereas volume tables must show u.b. volumes against o.b. dimensions. This requirement and the effect of variations in bark thickness and the root swell make it impossible to prepare universal volume tables directly from taper tables; form class must first be brought

into relationship with o.b. dimensions and root swell allowed for in separate tables for each species. This is carried out as follows :—a table is prepared—from data obtained in the manner explained on p. 45—showing the amounts by which the under-bark girths at breast height have been swollen above normal by root swelling. The amount of bark is determined from bark percentage tables (See Appendix I). With the figures thus obtained the form class for any over bark dimension is calculated from the formula

$$\frac{\text{girth at mid-point under bark}}{\text{normal g.b.h.u.b.}} = \text{form class.}$$

Mr. Macdonald's (5) investigations show that, as regards British conifers, very few trees under 25 ft. high have their form affected by root swell, whereas nearly all trees over 30 ft. high are so affected.

The information is tabulated as shown below.

Extract from a table for the determination of the form class of Norway Spruce (Macdonald. Forestry, Vol. VIII)

g.b.h.o.b. inches	g.o.b. in inches at mid-point between breast height and tip. 8	9	10	11	12	13	14	15	16	17	18	19	20
	Form Class												
16	·525	·575	·650	·700									
18	·450	·525	·575	·625									
20		·475	·525	·575		etc.		etc.	etc.				
22		·450	·500	·525									
24			·475	·500									
etc.													

Since bark thickness and root swell variations are different for different species, separate volume tables have to be prepared for each species, as shown below.

Extract from Form Class Volume Table Norway Spruce (Macdonald)

g.b.h.o.b. inches	Height class feet	Form Class 60	65	70	75	80
		u.b. Volume cubic feet (timber to 3 ins. diameter)				
16	40	1·9	2·0	2·3	2·5	2·8
	50	2·3	2·5	2·8	3·0	3·4
18	40	2·6	2·7	3·0	3·3	3·6
	50	3·1	3·4	3·7	4·0	4·4
20	40	3·3	3·4	3·8	4·1	4·5
	50	3·9	4·2	4·6	4·9	5·4
	60	4·6	4·9	5·4	5·9	6·5
40	70	22·1	24·1	25·5	28·6	31·2
	80	24·9	26·4	28·7	31·0	33·8
	90	27·7	29·8	32·1	34·6	37·9

Application. — The above two tables could be applied to determine the volume of felled trees, but are of little use for standing trees. Being based on average bark thickness and root swell they would not give sufficiently accurate results if applied to single trees, and the necessity for measuring the girth at a considerable height above ground level to determine the form class would exclude their application to computing the volumes of a large number of trees. In order to use a form-class volume table for standing trees, a simple method of accurately determining the form class must be discovered. Two methods have been used.

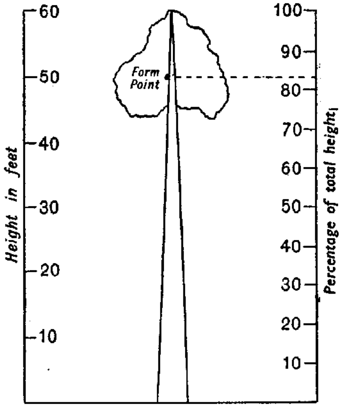


FIG. 24. Determination of the form point.

Method I.—According to Metzger's theory, exposure affects the form of the trees, that is to say the form should vary according to the density of the crop; the denser the crop the more cylindrical should be the form and the higher the form class. Working on this principle Jonson *estimated* form classes as follows for conifers in general.

Poor density	575 to 625
Fair density	650
Good density	675 to 700
Overcrowded Pine	700 to 725
Overcrowded Spruce	725 to 750

Method II (Form Point Method).—The **form point** is that point in the crown at which the wind pressure can be considered

as being concentrated, and it corresponds generally with the centre of gravity of the crown as seen from the side (*Fig.* 24). A form point is expressed in accordance with its position as a percentage of the total height of the tree above ground; thus in *Fig.* 24 the form point is 83.

The position of the form point is found by visual estimate and its height determined by means of a Christen's hypsometer graduated in percentages. Since, in accordance with Metzger's theory (p. 9), it is the wind pressure on the crown which is the main factor in influencing the form of the stem, and since, as has been shown in Chapter I, there is a constant relationship between the form of the stem and the form quotient, it is reasonable to suppose that there is a relationship between the position of the form point and the form quotient, and that the higher the form point the higher will be the form class. The relationships can be established by measurements on felled trees. In Sweden volume tables on this basis have been drawn up and are in general use.

Extract from a Swedish Volume Table

(Dr. M. L. Anderson in the Scottish Forestry Journal, Vol. 41)

d.b.h.o.b cms.	Height metres	Form Class ·500	·550	·575	·600	·625	·650
		Volume cubic metres.					
68	16	2·24	etc.				
	17	2·36	etc.				
	18	—					
	etc.						
Form Point Nor. Spruce		33	42	46	51	56	etc.

In the dense even-aged plantations of Great Britain it has not been found possible to obtain a sufficiently clear view of the crowns of the trees to utilise the form point method of determining the form class.

CHAPTER VI

THE INCREMENT OF INDIVIDUAL TREES

Definition.— Increment is the growth in height, diameter and volume of a tree in relation to time. Annual growth is known as **current annual increment** (C.A.I.). Though this term is commonly used in connection with volume increment, one year's growth is generally too small for accurate measurement and, depending as it does on the conditions of one growing season, of little practical significance. Growth is normally measured over a period of years and the average, obtained by dividing the total growth by the number of years in the period, should, strictly speaking, be referred to as the *periodical mean annual increment* (P.M.A.I.). C.A.I. is, however, the expression most often used in forestry and, in practice, always relates to the average annual increment over a short period, usually 5 or 10 years. If the time to which growth is related is the age of the tree, then the average growth, obtained by dividing the total growth by the age, is known as the **mean annual increment** (M.A.I.).

A. AGE

It is clear that no calculation of the mean annual increment is possible without first determining the age. The only certain method of determining the age of a standing tree is from records. A rough estimate may be made from the size and shape of the stem or crown, or from the colour and condition of the bark. The estimate is easier to make in the case of trees whose branches grow in whorls, as it may be possible to count the internodes on a considerable proportion of the stem. Apart from records, the most accurate method of determining the age of a tree is to fell it and count on the stump the annual rings formed by the annual increases in radius. Such annual rings, however, are not visible in all trees. They are clearest in ring porous broad-leaved species and in conifers, in which the autumn wood is darker than the spring wood. The visibility of the rings may be increased by damping the surface, cutting on a slant, in the case of very narrow rings, or, in some cases, by the application of colouring matter. Owing to an interruption of growth by drought,

defoliage, etc., false rings may appear, but these generally do not run right round the tree.* In old trees, no measurable growth may be added towards the base of the tree in certain years.

The number of rings counted will only give the age of the tree above the cut. To obtain the total age the number of years, which the average seedling would take to reach the height of the cut, must be added.

Where trees do not produce annual rings, the increment, except in some cases height increment, can only be determined from a series of recorded observations.

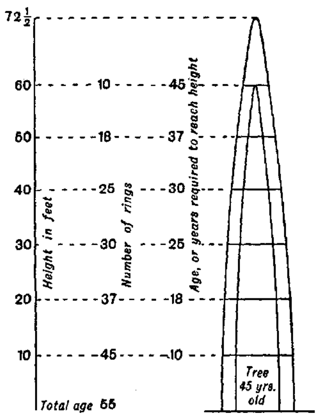


FIG. 25. Height and diameter increment.

B. HEIGHT INCREMENT

(i) Felled Trees — To determine the increment for, say, the last 10 years, cut off portions of the top of the tree until the point is found where there are exactly 10 rings, and measure the length from this point to the top of the tree. If, however, it is desired to obtain the increment for a number of periods or throughout the life of the tree, there is no necessity to cut sections representative of the periods required; the tree may be cut into any convenient sections as in *Fig.* 25. It is clear that the number of years taken by the tree to reach the height of any cut

* A ring which is not continuous is not necessarily a false ring. *Exact* determination of age requires special study of ring formation (12).

is represented by the total age of the tree (obtained from ring countings on the stump), less the number of rings at the cut. If the heights of each cut be plotted as ordinates over the corresponding number of years taken to reach these heights, as abscissæ, a graph can be drawn from which the height of the tree at any age can be read off (See Stem Analysis, Section F of this chapter).

(ii) **Standing Trees.**— In the case of trees which produce their side branches in whorls the height increment for a short period in the past may be determined by counting down from the tip the required number of internodes and subtracting the height to this point from the total height of the tree.

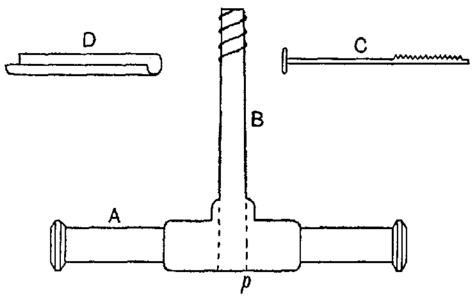


FIG. 26. Pressler's increment borer.

C. DIAMETER INCREMENT

(i) **Felled Trees.**— If the stem is sawn through at the point to be investigated, the diameter for any age may be determined and, as in the case of the height increment, the results may be graphed and growth curves obtained. For example, in *Fig.* 25 the outline of the tree at 45 years old is obtained by counting in 10 rings from the cambium and measuring the diameters at these points. The average of not less than 2 diameters taken at right angles to one another should be measured.

(ii) **Standing Trees.**— The diameter increment for a limited number of years in the past may be obtained immediately by means of Pressler's increment borer (*Fig.* 26). This instrument consists of a hollow handle "A," which contains the hollow borer "B," the graduated wedge "C" and the cradle "D," when these are not in use. The borer tapers slightly from the handle to the point. It is screwed into the tree at right angles to the latter's axis, thus forcing into its interior a cylinder of

wood. The wedge, the point of which is toothed along its inner edges, is then pushed tightly home between the inside edge of the borer and the wood cylinder at " p." The borer is given two or three reverse turns, thus separating the inner end of the wood cylinder from the tree; it is then screwed home again to drive the detached wood cylinder into the borer. The cylinder is removed with the wedge and laid in the cradle for measurement, which is carried out by means of the graduations on the wedge. The rings are counted and the diameter increment for a certain number of years in the immediate past thus determined. In view of the probability of the rate of growth varying on different parts of the circumference, the average of two or more measurements should be taken. The increment actually obtained by the borer

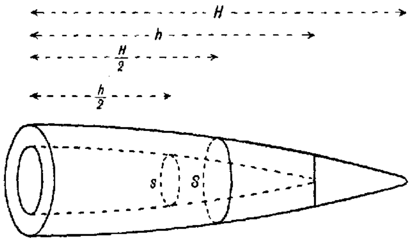


FIG. 27. Determination of stem volume increment.

is, of course, that of the radius, and must be doubled to obtain the diameter. If future increment is to be obtained by remeasurement, the tree must be given an identifying number, which is painted on the bark; or, alternatively, its position is fixed by triangulation or offsets on a plan, and the level at which the measurement is made is marked on the bark.

D. VOLUME INCREMENT

(i) **Felled Trees.** — The volume increment for the last few years, say 10, may be obtained roughly from the mid-section and height as follows (See *Fig.* 27). Measure the total height " H " and the mid-diameter, and determine the mid-sectional area " S." Cut back from the top of the tree until 10 rings are found, measure the length to the cut " h," and determine the mid-sectional area " s " at $\frac{h}{2}$, first sawing through the tree at this point and measuring from the tenth ring in from the cambium.

Then $I = V - v = S \times H - s \times h.$

Since " s " is necessarily calculated from the diameter, " S " should be calculated in the same way, using a calliper and, of course, measuring under bark. In Pressler's method the length corresponding to 10 years' growth is first cut off; " H " is placed equal to " h," and " S " and " s " are both measured at $\frac{h}{2}$: so that the formula becomes $I = (S - s)h$. The error due to omitting the top is held to be compensated for by " S " being measured further down the stem. Instead of sawing through the stem at $\frac{h}{2}$ an increment borer may be used to determine the smaller diameter. A more complete investigation of the volume increment of a tree is dealt with later under Stem Analysis in section F.

(ii) **Standing Trees.** — Pressler's borer may be used to determine the diameter " n " years ago and the two volumes calculated by means of form-factors, the height " n " years ago being estimated. The increment will be

$$(S \times H \times F) - (s \times h \times f)$$

E. INCREMENT PER CENT.

Definition.— The relation between the volume of a tree and its annual growth may be regarded in the same way as the relation between capital and interest. Thus the ratio of a year's growth to the volume at the commencement of the year represents a percentage and is called the current annual increment per cent. In practice the increment is measured over a period and the periodical mean annual increment per cent. is generally accepted as equivalent to the current annual increment per cent. Since the increment of each year is added to the wood capital, the calculation is a compound interest one and would be properly expressed by the formula

$$p = \left(\sqrt[n]{\frac{Cn}{Co}} - 1\right) 100$$

where " Co " is the measurement at the beginning of the period, " Cn " the measurement " n " years later, and " p " = the C.A.I. %.

This formula, which may be solved by logarithms, is seldom used, being replaced by the simpler formulæ for diameter and volume increment per cent. given below.

Objects of Determination. — Increment per cent. is very high in early youth and thereafter decreases throughout the life of the tree. The high rate of increment in youth is of no significance and this factor does not attain importance until trees have reached merchantable size. Thereafter the rate of increment is a useful guide in choosing the time for felling, par-

ticularly in deciding on the priority to be given in this respect to different mature trees or to mature trees in different woods. In estimating the future rate of increment it must be remembered that it will always be less than the present.

Formulæ for the Increment Per Cent.—(i) *Diameter Increment Per Cent.*—Pressler calculates the simple interest rate on the mean of the diameters at the beginning and end of the period instead of the compound interest on the diameter at the beginning of the period; thus

Where D = present diameter in inches,
d = diameter "n" years ago,
n = number of years in the period,
p = increment per cent.,

then on an average diameter of $\frac{D+d}{2}$ the annual increment = $\frac{D-d}{n}$ and on an average diameter of 100 the annual increment = $\frac{D-d}{D+d} \times \frac{200}{n}$

$$i.e.\ p = \frac{200\ (D-d)}{n\ (D+d)}$$ Formula 18 (Pressler's).

(ii) *Volume Increment Per Cent.*—This may be determined by calculating volumes as already stated in section D (ii) and substituting volumes for diameters in Formula 18 above.

$$i.e.\ p = \frac{200\ (V-v)}{n\ (V+v)}$$ Formula 19 (Pressler's).

where "V" and "v" are the volumes at the beginning and end of the period respectively.

This formula is more usually applied to woods; for single trees, in order to simplify the measurements, one of two formulæ, Pressler's or Schneider's, which assume that the height and form factor remain constant during the period, may be used. This assumption may be fairly correct when the formulæ are applied to mature trees, as is their intention. In this case volume is proportional to basal area and, on the analogy of Formula 18, we obtain

$$p = \frac{D^2 - d^2}{D^2 + d^2} \times \frac{200}{n}$$ Formula 20 (Pressler's).

Schneider introduced a further simplification as follows:—

$$p = \frac{400}{n\ D}$$ Formula 21 (Schneider's).

where D = present d.b.h.u.b. in inches,
and n = number of rings in the last inch of radius.

This formula may be evolved from Formula 20 on the assumption that " D " and " d " are separated by one year's growth only and that, in a large tree, there is so little difference between them that they may be considered equal; then Formula 20 may be simplified as follows:—

$$\frac{D^2-d^2}{\frac{1}{2}(D+d)^2}\times\frac{200}{n}=\frac{(D+d)\ (D-d)}{(D+d)\ (D+d)}\times\frac{400}{n}=\frac{D-d}{D+d}\times\frac{400}{n}$$

and, since the average annual diameter growth in the last " n " years $=\frac{2}{n}$ ins. $\therefore$ $D-d=\frac{2}{n}$ ins.

and, where one year separates " D " and " d," the formula becomes $\frac{\frac{2}{n}}{2D}\times\frac{400}{1}=\frac{400}{nD}$.

F. STEM ANALYSIS

Definition — *Stem analysis* is an investigation of the stem increment of a felled tree throughout its life. The record is available in any tree which produces distinguishable annual rings. In *Fig*. 25 (p. 58), investigations into height and diameter have provided graphic representations of a tree at the age of 55 and 45 respectively. The volume of the stem at these two ages is made up of a number of sections, which are assumed for mensuration purposes to be truncated parabaloids, with a cone at the top. The sections in this case are 10 ft. ones (except the top section). They are cut at their mid-lengths, namely, at 5, 15, 25 feet, etc., above the ground and the volume of each obtained from the formula $v=s\times h$, where " s " is the mean sectional-area obtained from the mean diameter. The top cone in the case of the 55 years' old tree is $12\frac{1}{2}$ ft. long and its volume will be

$$v=\frac{s\times 12\frac{1}{2}}{3}$$

" s " being the basal area.

It is clear that the form of the tree at any age may be similarly represented and its volume calculated.

Field Work

(Example tree illustrated in *Fig*. 30)

1. Select tree. Note species, locality and conditions of growth.
2. Measure g.b.h. or d.b.h. and mark place where measured.
3. Fell the tree as near ground as possible, and lop the branches.
4. Measure total height from b.h. and add 4 ft. 3 ins. Enter total height in note-book to the nearest foot. h = 104 ft.

5. Count rings on stump and add for time taken to reach stump height. *Total age* 65.
6. Mark the point where the diameter over bark =3 ins. (in order to separate the timber from small wood). Measure height to this point = 92 ft.
7. Having decided on the desirable length of section—in this case, timber length being 92 ft., we may have 8 10-foot sections and 2 6-foot sections—mark the centre of each section, *i.e.* at 5 ft., 15 ft., 25 ft., 35 ft., 45 ft., 55 ft., 65 ft., 75 ft., 83 ft. and 89 ft.
8. Cut sections about 2 ins. thick at the above points and at b.h. and at 92 ft., the upper cut being at the point marked. Mark the sections on their under sides as follows, at 4 ft. 3 ins. " B.H.," at 5 ft. " I," at 15 ft. " II," and so on, and at 92 ft. " Top."
9. Remove the above 12 sections to the workshop and plane the unmarked surfaces, *i.e.* the upper ones on which the rings are to be counted.

Tabulation of Results

Height Increment

Count the rings on each section and prepare the following table.

Section	Height in feet	Number of rings	Age corresponding to height
Stump	0	65	0
I	5	61	4
II	15	55	10
III	25	52	13
IV	35	48	17
V	45	45	20
VI	55	40	25
VII	65	35	30
VIII	75	30	35
IX	83	23	42
X	89	16	49
Base of cone	92	14	51
Top	104	0	65

From the above prepare the Height Graph *Fig.* 28.

The first step in the preparation of the graphic representation of the tree can now be carried out. Take a piece of section paper and mark on the central axis of the tree AB (See *Fig.* 30) the heights of the tree for ages of 0, 10, 20, etc., obtaining these figures from the height graph, as follows:—

Age	Height	Age	Height
10	15	40	81
20	45	50	91
30	65	60	99
		65	104

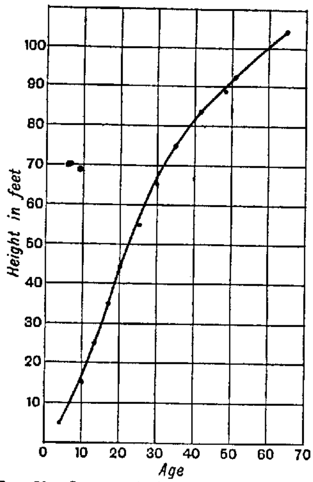


FIG. 28. Stem analysis. Age-height graph.

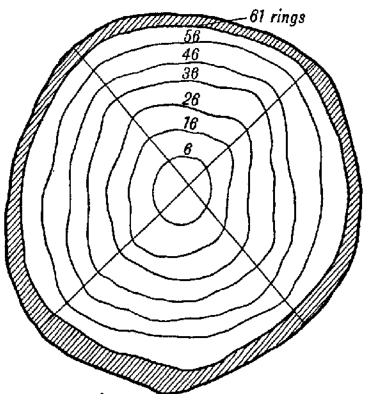


FIG. 29. Stem analysis. Cross-section of stem at 5 feet above ground level.

Diameter Increment

Take each section in turn. Draw *at least* two diameters (at right angles to one another) so as to obtain a mean diameter; count in from the cambium on each diameter the number of rings by which the age of the tree exceeds a round number—in this case 5 rings as the tree is 65 years old—mark these points and then count in 10 rings and again 10 rings and so on. (See *Fig.* 29), illustrating the procedure on the section at 5 feet above ground. The measurements are tabulated as follows:

	B.H. Section		No. I Section		No. II Section		No. III Section	
Age	Rings	Average Diameter in inches	Rings	Average Diameter in inches	Rings	Average Diameter in inches	Rings	Average Diameter in inches
65	over bark	19·55	over bark	19·18	over bark	16·70	over bark	15·68
65	62	18·48	61	18·22	55	16·06	52	15·10
60	57	17·46	56	17·20	50	15·20	47	14·08
50	47	15·70	46	15·40	40	13·11	37	12·10
40	37	13·81	36	13·45	30	10·90	27	10·17
30	27	11·25	26	10·90	20	8·70	17	7·62
20	17	7·40	16	17·00	10	4·90	7	3·60
10	7	1·82	6	1·40				

	No. IV Section		No. V Section		No. VI Section		No. VII Section	
65	over bark	14·40	over bark	12·76	over bark	11·40	over bark	9·44
65	48	13·80	45	12·20	40	10·90	25	9·12
60	43	12·70	40	11·25	35	9·92	30	8·05
50	33	10·65	30	9·10	25	7·40	20	5·90
40	23	8·58	20	6·85	15	4·95	10	2·60
30	13	6·05	10	4·10	5	2·10		
20	3	2·40						

	No. VIII Section		No. IX Section		No. X Section		Top Cone	
65	over bark	7·48	over bark	5·64	over bark	3·68	over bark	3·22
65	30	7·22	23	5·32	16	3·60	14	3·14
60	25	5·98	18	4·11	11	2·20	9	1·60
50	15	3·90	8	2·00	1	0·20		
40	5	1·22						

Volume Increment

The average diameters as above may now be scaled off against the central axis of the tree in *Fig.* 30 at the mid-height of the respective sections, and the tree form completed. In the illustration one half only of the tree has been represented and the form of the tree below 5 ft. has been omitted, as it is not required and no measurements have been made on the stump.

The volume of the tree at different ages may now be computed, remembering that wood below 3 ins. in diameter is not classified as timber; thus, at 10 years old, the tree contains one 10 ft. section in the form of a parabaloid and a cone-shaped section 5 ft. long. The former has a mid-diameter of 1·40 in., resulting in a sectional area of 0·0107 square feet and a volume of 0·107 cubic feet; the latter has a basal diameter of 0·60 in., a

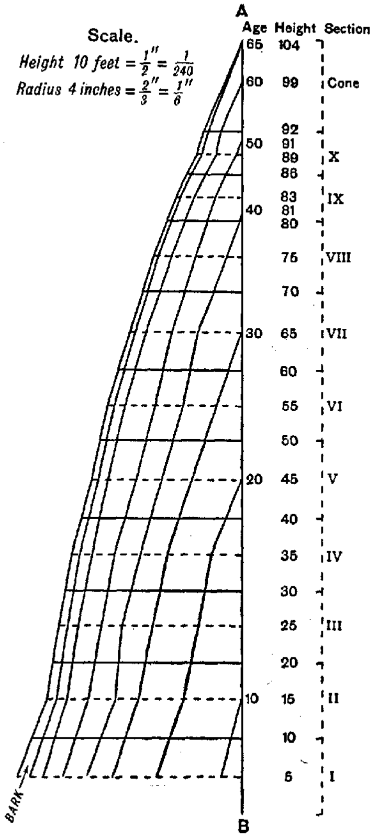


FIG. 30. Graphic representation of stem analysis (vertical section one-half of the stem).

basal area of 0·002 square inches and a volume of $\frac{5}{3} \times 0{\cdot}002 = 0{\cdot}003$ cubic feet (too small to be taken into consideration). Volumes may be tabulated as follows.

Section No.	Diam. inches	Sectional Area sq. ft.	Length feet	Volume cubic feet		Diam. inches	Setional Area sq ft.	Length feet	Volume cubic feet
Tree 65 years old including Bark.						Tree 65 years old excluding Bark.			
I	19·2	2·011	10	20·11		18·2	1·807	10	18·07
II	16·7	1·521	10	15·21		16·1	1·414	10	14·14
III	15·7	1·344	10	13·44		15·1	1·244	10	12·44
IV	14·4	1·131	10	11·31		13·8	1·039	10	10·39
V	12·8	·894	10	8·94		12·2	·812	10	8·12
VI	11·4	·709	10	7·09		10·9	·649	10	6·49
VII	9·4	·482	10	4·82		9·1	·452	10	4·52
VIII	7·5	·307	10	3·07		7·2	·283	10	2·83
IX	5·6	·171	6	1·03		5·3	·153	6	·91
X	3·7	·075	6	·45		3·6	·071	6	·43
Total Timber and Bark				85·47		Total Timber		...	78·34
Top	3·2	·056	12	·22		3·1	·052	12	·21
Total Timber—bark & small wood				85·69		Total Timber & small wood ...			78·55
Tree 60 years old.						Tree 50 years old.			
I	17·2	1·614	10	16·14		15·4	1·294	10	12·94
II	15·2	1·260	10	21·60		13·1	·936	10	9·36
III	14·1	1·084	10	10·84		12·1	·799	10	7·99
IV	12·7	·880	10	8·80		10·7	·625	10	6·25
V	11·3	·697	10	6·97		9·1	·452	10	4·52
VI	9·9	·535	10	5·35		7·4	·291	10	2·91
VII	8·1	·358	10	3·58		5·9	·190	10	1·90
VIII	6·0	·196	10	1·96		3·9	·083	10	·83
IX	4·1	·092	6	·55					
Total Timber				66·79		Total Timber ...			46·70
X	2·2	·026	6	·16	(IX)	2·0	·022	6	·13
Top	1·6	·014	7	·03		1·3	·009	5	·02
Total Timber and small wood				66·98					46·85
Tree 40 years old.						Tree 30 years old.			
I	13·5	·994	10	9·94		10·9	·648	10	6·48
II	10·9	·648	10	6·48		8·7	·413	10	4·13
III	10·2	·568	10	5·68		7·6	·315	10	3·15
IV	8·6	·403	10	4·03		6·1	·210	10	2·10
V	6·9	·260	10	2·60		4·1	·092	10	·92
VI	5·0	·136	10	1·36					
Total Timber				30·09		Total Timber ...			16·78
VII	2·6	·037	10	·37	(VI)	2·1	·024	10	·24
Top	2·2	·026	11	·10		1·2	·008	5	·01
Total Timber and small wood				30·56		Total Timber and small wood ...			17·03
Tree 20 years old.						Tree 10 years old.			
I	7·0	·267	10	2·67		1·4	·011	10	·11
II	4·9	·131	10	1·31		Top negligible ...			·00
III	3·6	·071	10	·71					
						Total small wood			·11
Total Timber				4·69					
IV	2·4	·031	10	·31					
Top	2·2	·026	5	·04					
Total Timber and small wood				5·04					

At 65 years old the volume of bark is 85·69 − 78·55 cubic feet = 7·14 cubic feet or 8·3% *of the total volume.*

The volume of wood for intermediate years may be obtained by preparing a graph with the above volumes as ordinates over the ages as abscissæ, as in *Fig.* 31.

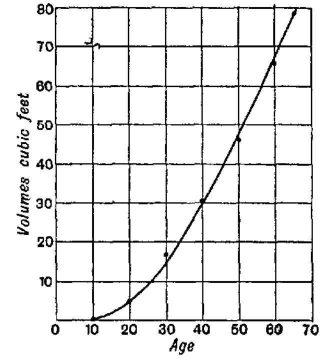


FIG. 31. Stem analysis. Age-volume graph.

The information obtained from the above analysis may be tabulated as follows. Such figures are, of course, of no particular value when obtained from one tree only.

Age	d.b.h. o.b. inches	d.b.h. u.b. inches	Height in feet	Volume in cubic feet: Timber	Small Wood	Total	Stem form factor	Volume Increment: C.A.I.	M.A.I.
10		1·8	15		0·11	0·11			0·01
								0·49	
20		7·4	45	4·69	0·35	5·04			0·25
								1·20	
30		11·3	65	16·78	0·25	17·03			0·57
								1·35	
40		13·8	81	30·09	0·47	30·56			0·76
								1·63	
50		15·7	91	46·70	0·15	46·85			0·94
								2·01	
60		17·5	99	66·79	0·19	66·98			1·12
								2·31	
65	19·6	18·5	104	78·34	0·21	78·55	·36		1·20

Column 3 in the above table is of no direct use since the d.b.h. of standing trees is always measured over bark. In order to fill up column 2, which it what is required, it will be necessary to measure bark thickness on a number of trees of corresponding diameters. The thickness of the bark is generally expressed as a

percentage of the *total* diameter or girth, this percentage usually being found to decrease with the increase in girth. The bark as a percentage of the diameter is obtained from Formula 13 (p. 23), viz. :—

$$p = \frac{\text{d.o.b} - \text{d.u.b.}}{\text{d.o.b.}} \times 100$$

The bark percentage for the 65 year old tree, the only one for which the data are available, is 5·6. If the percentage for the 60 year old tree is 6, then d.o.b. will be found as follows:

$$6 = \frac{\text{d.o.b.} - 17{\cdot}5}{\text{d.o.b.}} \times 100$$

$$\textit{i.e. } \text{d.o.b.} = 18{\cdot}6 \text{ ins.}$$

Until the data for column 3 have been obtained, it is not possible to fill in the form factors from the formula $f = \frac{V}{s \times h}$

As regards this particular tree the following observations may be made.

(i). It has evidently been a dominant tree at least since the age of 10.

(ii). As one would expect from a dominant tree and a persisting rapid height growth, it has a very conical form, as evidenced by the form factor.

(iii). The proportion of bark—8·3% of the volume—is very low, 12% is about the average for Douglas Fir.

(iv). The volume increment is still, at the age of 65, a long way from the maximum, as evidenced by the fact that the C.A.I. is still rising.

CHAPTER VII

THE MEASUREMENT OF WOODS

A. THE CLASSIFICATION OF WOODS

Since methods of measurement and the theories on which they are based depend to some extent on the number of age classes present in the wood to be measured, for mensuration purposes it is convenient to adopt the following definitions.

(i) *Even-aged woods.*—Woods in which all the trees are of the same age. Such woods are usually derived from planting, sowing or coppicing, after clear felling.

(ii) *Regular woods.*—In these there may be considerable differences in the ages of the individual trees, but, before maturity is reached, these differences will no longer be evidenced by the varying heights of the crowns. Such woods are usually derived from natural regeneration with a comparatively short regeneration period and, in silvicultural terminology, are often called even-aged.

(iii) *Irregular woods.*—These contain a large number of age gradations intermixed and the differences in age are evidenced in the varying heights of the crowns throughout the rotation. Such woods are derived from methods of natural regeneration involving a long regeneration period, the best example being provided by the selection method, which results in all age gradations being represented on a small area.

B. DETERMINATION OF THE AGE OF WOODS

In some cases records may be available from which the age of a wood can be obtained. In others the age must be derived from that of the age of individual trees, of which the methods of determining the age have been dealt with in Chapter VI. In the case of even-aged woods the age may be obtained from a single tree, in other cases the *mean age* must be obtained from several sample trees, which usually have to be felled. This mean age may be calculated in different ways, which may yield different results. The position will be clarified by defining mean age. Schlich defines the mean age of an uneven-aged wood as "*that period which an even-aged wood requires to produce the same volume as the uneven-aged wood.*" This definition correctly introduces the economic factor — for generally it is the economic age with which we are concerned—and, if applied to regular woods, it might be considered correct; but, if applied to

irregular woods, its accuracy is doubtful. Such woods develop differently from even-aged or regular woods and whether or not they produce the same volume in the same time is still a matter of controversy. By definition of M.A.I. the mean age of a wood is its volume divided by its M.A.I. and the mean age of an uneven-aged wood may therefore be defined as *the sum of the volumes of its age classes divided by the sum of the M.A.I.'s of these age classes.** This definition correctly takes into account the fact that volume is correlated with age. Expressed in formula form it will read:

Method (1). $$A = \frac{V_1 + V_2 + V_3 + \ldots}{\frac{V_1}{a_1} + \frac{V_2}{a_2} + \frac{V_3}{a_3} + \ldots}$$ **Smalian & Heyer's Formula.**

As a means of obtaining the mean age this method is cumbersome, involving, as it does, the previous calculation of volume. It is suitable for use in temporary sample plots (See p. 88), where the plot can be felled.

On the principle that basal area is the chief component of volume the above method may be simplified in practice by substituting this for volume; thus:

Method (2). $$A = \frac{(s_1 \times a_1) + (s_2 \times a_2) + (s_3 \times a_3) + \ldots}{S}$$

where s_1, s_2, s_3, etc., are the basal areas of the different age classes and S that of the total crop.

Method (3). $$A = \frac{m_1 \times a_1 + m_2 \times a_2 + m_3 \times a_3 + \ldots}{M}$$

Gumpel's Formula.

where M is the total area: and m_1, m_2, etc., are the areas occupied by each age class. It can only be applied where age classes occupy distinct areas. It gives fairly accurate results if the differences of age are small.

Method (4). $$A = \frac{n_1 \times a_1 + n_2 \times a_2 + n_3 \times a_3 + \ldots}{N}$$

André's Formula.

In this formula numbers of trees are substituted for areas.

Method (5). The mean age may be stated as the mean age of a number of selected sample trees representing the different age classes; thus:

$$A = \frac{a_1 + a_2 + a_3 + \ldots}{n}$$

where a_1, a_2, a_3, etc., represent the ages of the sample trees and

* Age classes:—Trees falling within definite age limits grouped together for purposes of management.

n their number. This is the most practicable method where it is not possible to fell a large number of trees.

In theory the accuracy of the methods, not based on volume, will depend on the condition of the wood in question. Where the range of ages is not a wide one, any of the last three methods may give sufficiently accurate results; but the measure of inaccuracy of a method is the extent to which its result differs from that given by method (1), and, where there are wide differences in age, this may be considerable. This may be illustrated by taking an extreme example of two age classes as follows :—

Age	Volume	M.A.I.
10	10	1
100	2000	20

By method (1) $A = \frac{2000+10}{20+1} = 95{\cdot}7$

(5) $A = \frac{100+10}{2} = 55.$

Obviously the first figure is more correct for all practical purposes. There is seldom, however, any useful object to be served in determining the mean age of woods which are silviculturally very unevenly aged, such as, for example, woods, produced by the selection and similar systems.

Method 5 can be improved in theory by taking a greater number of sample trees in the larger diameter classes, but this increases the importance of the personal factor in their selection and in practice the chief source of inaccuracy arises from the sample trees selected being not truly representative of the crop. Unless they occupy separate areas, the age classes represented in the crop can only be determined from the average age of sample trees felled in each size class. The grouping of the trees in diameter or girth classes is therefore generally a necessary preliminary to determining the mean age.

C. DETERMINATION OF MEAN HEIGHT

The mean height may be required for the purpose either of calculating volume or of assessing the quality of a wood (See Chapters VIII and IX). In the former case it will relate to all the trees, in the latter, it may relate to the dominant trees only. Where volume determination is the object the mean height may be defined as *the height which when multiplied by the mean form-factor and the mean basal-area of a wood gives the arithmetic mean-volume* $\left(i.e.\ h \times f \times s = \frac{\text{Volume of the wood}}{\text{number of trees in the wood}}\right)$ (2)

There is no method of determining the mean height which can

be counted on to comply with this definition, but the third method given below is likely to be the least inaccurate.

The mean height of each diameter class may be obtained by measuring the heights of a number of trees in the class and calculating the arithmetical mean height. The mean height of the crop is sometimes obtained in this manner, *i.e.* by the formula

$$H = \frac{n_1 \times h_1 + n_2 \times h_2 + n_3 \times h_3 + \ \ldots\ .}{N}$$

where n_1, n_2, n_3, etc., and h_1, h_2, h_3, etc., are the number and mean heights respectively of the trees in each class and N is the total number of trees measured.

Acting again on the principle that volume should be the basis of calculation, a more accurate method is to substitute basal areas for numbers and calculate the mean height of the crop from the formula:—

$$H = \frac{s_1 \times h_1 + s_2 \times h_2 + s_3 \times h_3 + \ \ldots\ .}{S}$$

Lorey's Formula.

A third method is to measure the heights of a number of representative trees in each diameter class and prepare a graph with the heights as ordinates over the diameters as abscissæ. From the curve the mean height of each diameter class can be read off, and the mean height of the wood is obtained from the formula:

$$H = \frac{mh_1 + mh_2 + mh_3 + \ \ldots\ .}{N}$$

where mh_1, mh_2, etc. = mean heights of the class and N = number of classes.

D. CALCULATION OF THE VOLUME OF UNIT WOODS

The methods of determining the volume of whole woods and forests will be dealt with in Chapter IX and, for the purposes of this chapter, it may be assumed that we are concerned only with the measurement of small *sample* or *unit woods* for management purposes and for the preparation of yield tables (See next Chapter). Such woods will generally not exceed one acre in extent and those measured for the latter purpose will be even-aged. They must be regular in shape, either rectangular or circular, so that their areas can be accurately computed. The volume of a plot may be determined by the application of volume tables applied as explained in Chapter V, *i.e.* the d.b.h. of all the trees in the plot is measured, their heights estimated and their volumes obtained direct from the tables according to the size class

in which they fall. Though this method may be suitable for general management purposes, *e.g.* stock taking (Chapter IX), it is not sufficiently accurate for the purposes of research. As will be shown later (Method IX), suitable volume tables can, however, be used in conjunction with sample trees.

In rare cases it is practicable to clear fell the plot and measure up the volume of the trees felled. This is the most accurate method. In most cases, however, only *sample* trees can be measured. There are three systems of utilising sample trees for the determination of the volume of the crop:

(a) The crop volume of the plot is calculated directly from the volume of *concrete* sample trees by the rules of proportion.
(b) The volume of the plot is calculated from the volume of *concrete* sample trees by graphic methods.
(c) The volume of the plot is calculated from *abstract* sample trees obtained from graphs and volume tables.

(a) The Volume of the Plot Calculated from the Volume of Sample Trees by the Rules of Proportion

(i) Selection of Sample Trees. — The sample trees are selected so as to represent the *mean tree* of the crop or of the size classes, or groups of size classes, into which the crop may be divided. In theory the mean tree should be that tree whose volume multiplied by the number of trees will give the total volume of the crop, class or group. Since volume has yet to be determined, the long established practice has been to substitute basal area for volume, to calculate the mean basal area tree and then to select sample trees of diameters as near as possible to the diameter equivalent to this mean basal-area. Further, most text books on mensuration prescribe that the sample trees should conform as closely as possible in height, stem form and shape of crown to the average of the class which they are supposed to represent. The selection of trees similar to other trees is in practice a difficult or impossible operation and makes the result too dependent on the personal factor. The same objection applies to the selection of a tree which shall have the mean height of the class, and the only satisfactory method of doing this is to measure a number of heights and calculate the arithmetic mean, where the diameter limits are small, or to prepare a diameter height graph where these limits are large. It seems, therefore, preferable to dispense with any attempt to select typical trees and—as recommended by Chaturvedi (2)—to choose rather abnormal trees, selecting, for example, the largest and smallest available in the class.* It will be seen that the basic idea underlying

* Mr. Macdonald (5) has found that among trees of the mean girth or mean height of the crop there is a range of form class almost as great as in the complete plot.

the earlier instruction in selecting sample trees was that, since volume depends on basal area, stem form and height, therefore a tree which has the mean basal area, height and form factor of the crop has also the mean volume. Chaturvedi has pointed out that this assumption is in contradiction to the mathematical facts and an additional reason for abandoning any attempt to select a mean sample tree is therefore provided.

(ii) **Number of Sample Trees.** — It is impossible to lay down any general rule as to the minimum number of sample trees required in varying circumstances. The greater the variation in size of the trees in the crop the larger the number of sample trees which will be required and, when measuring for scientific purposes, the greater accuracy demanded requires the selection of a larger number of sample trees than is the case when measuring for management purposes.

(iii) **Measurement of Sample Trees.** — Where possible, sample trees should be felled for measurement. In permanent sample plots used for the preparation of yield tables this involves selecting trees marked in thinnings or taking them for the neighbouring surround (See Chapter VIII, p. 99). Standing trees may be measured with the help of a ladder and the use of taper tables as described in Chapter IV. An alternative is to measure the height and use form factor tables, provided that any are available which are known to apply to the crop in question. If, however, suitable form factor or volume tables are available, it is probably preferable to use the method under heading (c) (See Method IX, p. 82), and thus avoid altogether the selection of concrete sample trees.

The following are examples of the best known methods which come under heading (a).

Method I. By 1 in. diameter classes. The trees are enumerated in 1 in. diameter classes and are tabulated as in columns 1 and 2 of Table I below.

1 Acre Scots Pine 70 years old.*

Table I. 1 in. diameter classes.

Diameter inches	Number of Trees	Basal area square feet	Sample Trees: Diameter inches	Sample Trees: Basal area square feet	Sample Trees: Volume cubic feet	Volume inch classes cubic feet
8	5	1·75	8·5	·394	7·26	32
9	10	4·42	9·3	·472	12·13	114
10	30	16·36	10·7	·625	17·14	449
11	40	26·40	11·0		16·19	648
12	50	39·27	12·1	·799	22·40	1101
13	45	41·48	13·1	·936	25·93	1076
14	30	32·07	15·0	1·227	27·79	726
15	20	24·54	15·0		28.40	568
16	10	13·96	16·4	1·467	38·53	367
Total	240	200·25				5081

The figures used in Methods I to IV and VII are obtained from those given in Schlich (Vol. III. 5th Edition) for a 1 acre Scots Pine wood.

Column 3 is then filled in from a table (Appendix III); one or more sample trees are selected for each diameter class, their diameters measured and entered in column 4, column 5 is filled in from a table, and the volume of the sample trees is measured and entered in column 6. The volume of each class is then calculated from the formula

$$V = \frac{v \times S}{s}$$

where V = volume of the diameter class.
v = volume of the sample tree or trees.
S = basal area of the diameter class.
s = basal area of the sample tree or trees.

This method is now little used since it requires the measurement, and perhaps the felling, of a large number of sample trees. It also has the defect that a sample tree represents a greatly varying number of trees, thus in this example a sample tree in the 8 in. class represents only 5 trees, whereas in the 12 in. class it represents 50 trees.

Method II. Arithmetical mean-tree.

This is a modification of Method I introduced to reduce the number of sample trees required and to remove the defect pointed out in that method. The first part of the procedure up to the filling in of columns 1 and 2 of Table I are the same as before. The basal area of the mean tree of the plot is found by dividing the total basal area of the plot by the total number of trees: thus $\frac{200{\cdot}25}{240} = {\cdot}834$ sq. feet, which is entered in col. 3 of Table II. The equivalent diameter of this basal area, 12·4 inches, is entered in column 4. Suitable sample trees, having diameters as near as can be found to this diameter are selected (column 5). The calculation of the volume is made as in Method I, *i.e.*

$$V = \frac{64{\cdot}68 \times 200{\cdot}25}{2{\cdot}607} = 4{,}968 \text{ cubic feet.}$$

Table II. Arithmetical Mean Tree.

		Mean Tree		Sample Trees			
Number of Trees	Basal area square feet	Basal area square feet	Diameter inches	Diameter inches	Basal area square feet	Volume cubic feet	Total Volume cubic feet
				12.1	·799	20·41	
				12·1	·799	22·40	
				13·6	1·009	21·87	
240	200·25	·834	12·4		2·607	64·68	4968

Method III. Groups containing an equal number of diameter or girth classes (Huber, 1824).

This method is an intermediate one between Methods I and II, introduced to give greater accuracy than Method II and to reduce the number of sample trees required by Method I.

Several classes are grouped together and a mean tree calculated for each group. Thus in Table I three groups might be formed, 8 ins. to 10 ins., 11 ins. to 13 ins., etc. The method of procedure is exactly the same for each group as for the one group in Method II. The method re-introduces the defect pointed out in Method I, that of making a sample tree represent a varying number of trees.

Method IV. Urich's Method (1860 and 1881).

Urich proposed to remove the defect, pointed out in Methods I and III, by dividing the classes into groups so that there should be approximately the same number of trees in each group, and an equal number of sample trees measured for each group. The mean tree of each group is calculated and the sample tree selected in the same way as in the last method. Since each sample tree represents the same number of trees, it is unnecessary to calculate separately the volume of each group. The volume of the wood is obtained from one calculation.

$$V = \frac{\text{Total volume of sample trees} \times \text{Sectional area of the wood}}{\text{Total sectional area of sample trees.}}$$

See the example given in Table III.

I Acre Scots Pine Wood 70 years old.

Table III. Urich's Method.

Group	Diameter class and number of trees	Basal area sq. ft.	Mean Tree: Basal area sq. ft.	Mean Tree: Diam. inches	Sample Trees: Diam. inches	Sample Trees: Sect. area sq. ft.	Sample Trees: Volume cu. feet	Volume of wood cubic feet
	8″ = 5	1·75						
I	9″ = 10	4·42						
	10″ = 30	16·36			9·6	·503	11·63	
	11″ = 35	23·10			10·7	·624	17·14	
	80	45·63	·57	10·2				
	11″ = 5	3·30						
II	12″ = 50	39·27			12·1	·799	22·40	$V = \frac{133·29 \times 200·25}{5·316}$
	13″ = 25	23·04			13·1	·936	25·93	
	80	65·61	·82	12·3				
	13″ = 20	18·44						
III	14″ = 30	32·07						
	15″ = 20	24·54			15·0	1·227	27·79	
	16″ = 10	13·96			15·0	1·227	28·40	
	80	89·01	1·11	14·3				
Total	240	200·25				5·316	133·29	5021

Method V. Hartig's Method (1868).

Errors in measurement are proportionate to volume and may be plus or minus. If there are equal volumes in each group and if there is an equal number of groups and the same number of sample trees in each group, there is a reasonable prospect that these errors may cancel one another. This is the basis of

Hartig's method. Since it is impossible to form groups of equal volume before the latter have been calculated, Hartig forms an even number of groups of equal basal area. His method is illustrated in Table IV below. The volume of each group must be calculated separately from the formula

$$V = \frac{v \times S}{s}$$

Thus for group I $$V = \frac{29{\cdot}27 \times 50{\cdot}50}{1{\cdot}097}$$

Table IV. Hartig's Method.

Group	Diameter and number of trees		Basal area sq. ft.	Mean Tree		Sample Trees			Volume of group
				Basal area sq. ft.	Diam. inches	Diam. inches	Basal area sq. ft.	Volume cu. ft.	
	8″	5	1·75						
	9″	10	4·42						
I	10″	30	16·36			9·3	·472	12·13	
	11″	40	26·40			10·7	·625	17·14	
	12″	2	1·57						
		87	50·50	·58	10·3		1·097	29·27	1478
	12″	48	37·70						
II	13″	13	11·98			12·1	·799	22·40	
						12·1	·799	20·41	
		61	49·68	·81	12·2		1·598	42·81	1331
	13″	32	29·50						
III	14″	19	20·31			13·1	·936	25·93	
						13·6	1·009	21·87	
		51	49·81	98	13·4		1·945	47·80	1224
	14″	11	11·76						
IV	15″	20	24·54			15·0		27·79	
	16″	10	13·96			15·0		28·40	
		41	50·26	1·23	15·0			56·19	1152
Total		240	200·25						5185

Method VI. Block's Method.

The methods of grouping already given have been objected to for permanent sample plots on the ground that the groups will not contain the same trees at each measurement, and that trees which will form the final crop are grouped together with trees which are certain to be removed in thinnings. Under a system of grouping introduced by Block in 1889 these objections were met by grouping the trees so that the largest were placed in Group I, and next largest in Group II and so on, a greater number of trees being placed in the lower groups and the residue in the last group. The table below, showing the standard grouping adopted by the B.F.C., illustrates the procedure.

Area of Plots	Group No.									
	1	2	3	4	5	6	7	8	9	10
	Number of trees in each group.									
0·75 acre or over	50	50	50	50	100	100	100	200	200	200
0·3 to 0·75 acre	20	20	20	20	40	40	40	80	80	80
Under 0·3 acre	10	10	10	10	20	20	20	40	40	40

It will be seen that this method of grouping tends towards a separation of the growing stock into groups representing the material removed in thinnings at different periods, and that removed in the final felling. Block also prescribed the selection of

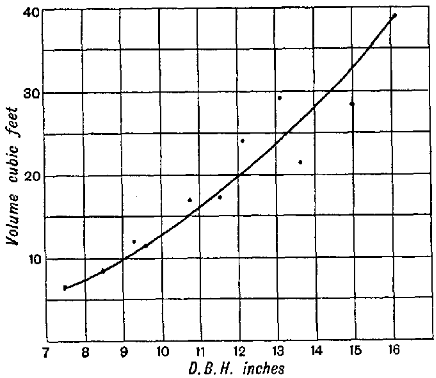


FIG. 32. Sample trees. Diameter-volume graph.

a greater number of sample trees for the groups containing the larger trees on account of the greater economic importance of the latter. The volume of each group is calculated as before from mean basal area sample trees, measuring not less than two for each group.

(b) THE VOLUME OF THE PLOT IS CALCULATED FROM THE VOLUME OF SAMPLE TREES BY GRAPHIC METHODS

In the methods hitherto described the sample tree is a tree selected on account of its near approach in size and form to the mean tree of the group, and the difference in the method lies only in the different systems of grouping. A sample tree, in fact,

only influences the data for the group for which it has been selected. An alternative method of dealing with the sample trees is to select them without regard to the grouping, but so as to cover the whole range of diameter classes. The sample tree data are then graphed and the information required for calculating the volume of the groups is obtained from the graphs.

Method VII. Volume Curve Method.

The volumes of the sample trees are plotted as ordinates over their diameters (or girths) as abscissæ, and a smooth curve drawn. The diameter of the mean tree of each group having been calculated, its volume is read from the graph and multiplied by the number of trees in the group, to obtain the volume of the group. Any method of grouping may be employed.

EXAMPLE (See *Fig.* 32).

Using Hartig's grouping (Method V) the following sample trees are measured :

Diameter in inches	Volume in cubic feet
7·5	6·62
8·5	7·26
9·6	11·63
11·5	17·43
12·1	20·41
13·1	25·93
15·0	28·40
16·1	38·53

The volume is calculated as follows (See Table IV) :—

Mean tree of group			
Diameter inches	Volume from graph cubic feet	No of trees in group	Volume of group cubic feet
10·3	14·0	87	1218
12·2	20·8	61	1269
13·4	25·3	51	1290
15·0	32·7	41	1341
	Total Volume		5118

Method VIII. Form Factor Method.

This method is similar to the last, but, instead of volumes, the form factors of the sample trees are calculated and plotted as ordinates over their diameters (or girths), and a smooth curve drawn. Diameter-height graphs are also prepared. The diameter of the mean tree of each group is then calculated, its form factor and mean height read from the above graphs and its volume obtained from the formula.

$$V = s \times h \times f.$$

(c) The Volume of the Plot is Calculated from Abstract Sample Trees Obtained from Graphs and Volume Tables

Method IX.

Any of the methods of grouping already given, including the 1 in. diameter class method, but excluding the arithmetical mean sample tree method, may be used. No concrete sample trees are selected, but a height-d.b.h. graph is prepared from height measurements of a number of trees in each group and these trees should be well spread over the wood so as to include all variations in growth. The mean diameter tree of each group is then calculated as before, its height read from the graph and the volume of a tree of that diameter and height read from the volume table. The volume of the groups and plot is then obtained from these abstract sample trees by multiplication.

The pre-requisite for the use of this method is the existence of suitable volume tables. Either diameter-height or form-class volume tables are suitable. If the former are to be used, in considering their suitability it must be remembered that volume depends on d.b.h., height and form, and that it is the first two of these factors which the volume table directly takes into account. Form depends on environment and age; so that, unless the tables in question have been prepared for trees grown on a similar locality, under a similar silvicultural system and of the same age, they may not be accurate. On the other hand, the fact that the volume obtained for an abstract sample tree may not be the volume of any actual tree in the crop does not militate against the accuracy of the total volume calculations; and, if a large number of groups are made, involving a correspondingly large number of sample trees, errors in different groups are likely to be compensating. If form-quotient tables are used, a practical method of determining the form-quotient must be devised; in many cases it would be practicable to use a ladder to measure the mid-diameters.

(d) Merits of the Different Methods of Determining the Volume of a Wood

Methods II, III and IV are suitable for general management purposes for obtaining the volumes of sample areas in stock-taking (Chapter IX). Method V (Hartig's) is likely to give a higher degree of accuracy and is used by the B.F.C. for determining the volume of temporary sample plots for the preparation of yield tables. For permanent sample plots, for the reasons already given, a different system of grouping is to be preferred and the B.F.C. and a number of other Research Institutes use Block's (Method VI) or similar methods. For scientific work

graphic methods are to be preferred in dealing with the sample tree data and the B.F.C. use Method VIII for determining the volumes of the groups and Method VII as a check (10). It is probable that eventually, with an increase in knowledge and available data, volume tables (See Method IX) will be used in supersession of all other methods of calculating the volume.

CHAPTER VIII

YIELD TABLES

A. DEFINITION, OBJECTS AND CONTENTS OF YIELD TABLES

Some remarks have already been made in Chapter I regarding the origin and purpose of yield tables. A yield table may be defined as a *tabular statement which gives the course of development of an even-aged or approximately even-aged wood from early youth up to a certain age—generally the maximum rotation which would be adopted—at periodic intervals, usually of five or ten years*. Yield tables may be required to serve all or any of the following purposes :

(a) Determination of the volume and increment of woods.
(b) Determination of the qualities of locality.
(c) Forecasting the yield of forests.
(d) Deciding the most profitable species, method of treatment and rotation.
(e) Determination of the value of the soil, growing stock or both.

To serve purposes d and e, money yield must usually be substituted for volume yield, leading to the preparation of money yield tables, which is dealt with under Forest Valuation.

In order to meet the above requirements, yield tables should show, per unit of area (acre) :

(1) The number of trees.
(2) Mean d.b.h. or g.b.h.
(3) Total basal area.
(4) Mean height.
(5) Volume of main crop.
(6) Volume of thinnings.
(7) Form factors.

Columns are sometimes added for the C.A.I. and M.A.I.

The manner of drawing up a set of yield tables is illustrated opposite.

Extract from Schwappach's Yield Tables for Beech. North Germany. (From Schlich)

Age	Main Crop: Mean Height feet	Main Crop: Mean Diameter at 4ft. 3in.	Main Crop: Number of Stems per Acre	Main Crop: Basal Area Square Feet per Acre	Main Crop: Form Factor	Main Crop: Volume Cubic Feet per Acre a	Thinnings: Volume Cubic Feet per Acre b	Thinnings: Sum of Thinnings c	Total Volume (a+b) d	C.A.I. $\frac{d-a}{10}$ e	M.A.I. $\frac{a+c}{age}$ f
Quality Class I, or Best.											
30	31	3·0	1,550	74	·30	690	—	—	690		23
40	45	4·5	940	105	·41	1,940	130	130	2070	138	51·75
50	56	6·3	600	131	·45	3,330	400	530	3730	179	77·20
60	67	8·0	423	148	·46	4,370	590	1,120	4960	163	91·50
70	76	9·5	316	156	·48	5,640	740	1,860	6380	201	107·15
80	85	10·9	249	161	·48	6,560	830	2,690	7390	175	115·63
Quality Class III, or Average.											
30	23	2·2	2,070	53	·07	90	—	—	90		3
40	33	3·3	1,390	81	·35	940	—	—	940	85	23·5
50	43	4·4	970	104	·45	2,000	90	90	2090	115	41·8
60	52	5·5	930	121	·46	2,920	270	360	3190	119	54·5
70	60	6·4	580	131	·47	3,720	330	690	4050	113	63
80	67	7·4	460	137	·48	4,430	360	1,050	4790	107	68·5
Quality Class V, or Lowest.											
40	20	2·3	2,000	57	·35	400	—	—	400		4
50	28	3·1	1,510	80	·42	930	—	—	930	53	18·6
60	34	3·7	1,200	98	·46	1,530	—	—	1530	60	25·5
70	39	4·4	1,000	108	·48	2,040	—	—	2040	51	29·14
80	44	5·0	830	115	·48	2,410	70	70	2480	44	31

NOTE.—Columns d, e and f have been added to the tables as originally drawn up. Note the method for calculating C.A.I., *e.g.*, between 40 and 50 years for I Quality the C.A.I. $= \frac{3730-1940}{10}$

A yield table may be either Local or General, according to whether the data for its preparation are all collected in one district or in similar localities in different districts. No rule can be laid down as to the extent of country over which data may be collected for the preparation of one set of yield tables, or as to the territorial limits of applicability.

The latter will gradually become apparent as the data are collected, by comparing those obtained from different areas. Generally speaking, the scope of yield tables can only be decided empirically, knowledge not yet being sufficient to provide a scientific basis for the decision (See *Classification of Sites*, below). It has, however, been found that even comparatively small areas usually include sites of varying quality, resulting in corresponding differences in the quantity and quality of tree growth; consequently a set of yield tables, even if a purely local one, will generally have to provide separate data for the several distinguishable localities, a subject which is discussed in the next section.

B. CLASSIFICATION OF SITES

The original purpose of yield tables was to provide information regarding the probable volume and increment per unit of area at various ages of existing woods, which were usually even-aged and of one species. The work was started in Germany and it was assumed that the species concerned were growing in localities which were naturally suited to them. This being the case, the division into quality classes was on a statistical rather than on an ecological basis, and the quality of a locality was assessed in accordance with its volume production under proper treatment. The number of quality classes recognised in any region depended on personal choice of the compiler of the yield table and had no scientific basis. Objections have been raised to the above method of recognition of and division into quality classes on the ground that there is nothing which can be distinguished in nature corresponding to these classes as such (Cajandar) (11). For example, a Quality II Locality for Oak indicates only a locality which is expected to produce a certain volume and increment of oak per acre. Two localities, quite different in ecological character, may yield identical statistical results and the classification of the locality provides no indication of the yield which may be expected from another species. Where yield tables are required solely for the purpose of forecasting the yield of existing woods, these objections may not appear to be of much importance; but, if it is intended that they should influence silviculture and policy, then an arbitrary classification of localities by volume production is inadequate. The need for an ecological basis of classification is particularly felt when afforestation projects have to be planned. Even when yield tables are used only for their original purpose there are objections to the volume method of classification. In the first place it assumes that the production of the maximum volume is the sole aim of management, or, at least, that the production of the maximum volume is never incompatible with obtaining the highest quality timber:

should the latter proposition be incorrect, then the quality of a locality might appear to change according to whether it was assessed by a volume or a money yield table. Further, when applying yield tables, a difficulty arises in assessing the quality of the locality, the yield of which is to be determined. The yield table figures apply to normally developed woods, which in an actual forest will make up a small percentage of the whole, so that the assessment of the quality may be largely a matter of personal opinion. This last difficulty has to some extent been got over by using height as an indicator of quality; for, of the factors which make up volume, height is the one which is least affected by minor variations in the past history and treatment of the woods.

The objections to the standard methods of classification have been fully dealt with by Cajandar (11), who has proposed a method of classification based on the character of the vegetation, mainly the ground vegetation, which would be universally applicable both for silvicultural and statistical purposes. Excepting in Finland, however, his method has not been found practicable, and, though it is possible that, working on the lines indicated by him, more natural and satisfactory methods of site classification will eventually be evolved, at present foresters continue to use the methods based on volume, or a component of volume such as mean height.

C. SAMPLE PLOTS

The data for yield tables are obtained from sample plots. The number required will depend upon the number of recognised quality classes and the size of the area to be investigated. For general yield tables it has been suggested that there should be not less than 30 sample plots for each quality class. They should be fully stocked, well distributed over the whole area, representative of all kinds of localities, and the growing stock should be of normal development. Normally developed fully stocked woods are usually confined to small scattered patches in any forest. This feature and considerations of expense will restrict the size of the plots. On the other hand, the smaller the plot the greater the importance of the individual tree, which is the unit for measurement, and, therefore, the greater the probable errors arising out of abnormalities or inaccuracies in measurement. This point is of special importance when plots are to be remeasured over a long period, during which the trees will increase in size and decrease in number. The plots should therefore be as large as possible. In practice the above considerations generally result in plots between 0·2 and 1·0 acre in area. The plots selected should be surrounded by a crop of similar growth. They may be either (a) permanent, (b) semi-permanent or (c) temporary.

(a) **Permanent Sample Plots.**— A permanent sample plot in an even-aged wood is one which is established when the wood is young and is remeasured at intervals usually up to rotation age. The use of permanent sample plots simplifies the classification of quality classes and provides the only means by which the effect of different treatments can be fully tested. It is desirable that the plots should be established not later than the time when the first thinning is required. The procedure in laying out and measuring permanent sample plots is described in section G.

(b) **Period Sample Plots.** — If investigations are confined to permanent plots, a whole rotation will be required before complete yield tables can be prepared. In order to accelerate the operation a number of plots are selected differing in age by a number of years, say 20, and the plots are measured at intervals until the complete series is obtained. The comparison of the statistical results necessary to allot the plots to the several quality classes can be made when the period representing the differences in age has elapsed and each wood has reached the original age of the next higher age gradation. Alternatively the classification can be made immediately by stem analysis as explained in section D.1, below. The procedure in laying out and measuring a semi-permanent plot does not differ materially from that of a permanent one.

(c) **Temporary Sample Plots.** — Yield tables can be prepared immediately by selecting plots covering the whole range of age gradations required and graphing the results. Yield tables prepared in this manner will, of course, only serve statistical purposes and their reliability for forecasting the yield will depend upon whether the woods in which the sample plots have been selected have been developed under the same treatment as that to which they will be subjected in the future. If temporary plots can be felled, accurate measurement is greatly facilitated and their usefulness in supplementing the data obtained from plots of a more permanent character may be considerable.

In practice the original yield tables in all countries were prepared at once by measurements obtained in a number of plots of different ages, some of which were abandoned after the first measurement and some, in the younger woods, kept up for future measurements. Thus all the methods used for preparing yield tables have to devise a procedure for classifying in the same quality class woods of different ages, whose past records are not available.

D. PROCEDURES IN PREPARING YIELD TABLES

Many different methods of classification of woods on a statistical basis and the preparation of yield tables therefrom have been evolved. The following are amongst the most important.

1. THE INDEX METHOD. (Schlich. Method based upon an indicating wood (1))

Invented by Seutter in 1796 and developed by various 19th century investigators, this method, in its final form, introduced by Theoder and Robert Hartig, depends on the stem analysis of the dominant trees in a mature wood. Acting on the assumption, more or less correct, that trees which are now dominant have been dominant throughout life, younger woods are then searched for, the dominant trees of which have the same dimensions as the dominant trees in the mature wood had at the same age. All such woods as show approximately the same development of the dominant trees are considered as belonging to the same quality class and sample plots are then selected therein and yield tables prepared from the measurements obtained. Schlich notes that the method is troublesome in execution. A classification based on height only would simplify it.

2. BAUR'S OR THE STRIP VOLUME METHOD

After a sufficient number of normal sample plots on localities belonging to various quality classes and stocked with woods of all ages have been measured, the volumes are marked as ordinates over the corresponding ages as abscissæ (*Fig.* 33). Two curves are then drawn, passing approximately through the highest and the lowest points. The space between the curves is divided into strips of equal breadth by curves drawn to conform in shape to the maximum and minimum curves, the number of strips varying according to the number of quality classes desired. By drawing a mean curve through each strip, the mean volume curve for the quality is obtained, and from this the volume column in the yield table is prepared. Graphs are also employed to obtain the mean height, girth, diameter and total sectional area and number of trees for entry in the yield table, the data for each of these items being taken for each quality class from the plots allotted to that class and plotted over the ages of the plots. Baur's method is easy of application and gives good results where a sufficient number of plots, *uniformly treated in the past,* are available. Where the woods have not been uniformly treated in the past and have been over or under thinned, as is the case with most British woods, the present volume may be a very inaccurate indicator of the productive capacity of the site. Another objection which has been advanced to Baur's method is that the trend of the curves is based upon what is inevitably the scantiest part of the data, namely, the fastest and slowest growing woods.

Example of preparing a Yield Table by Baur's Method. (Data from Schlich's Manual Vol. III).

Scots Pine: Three Quality Classes to be distinguished. Plots measured as follows. The figures are per acre.

No.	Age in years	No. of trees	s.b.h. sq. ft.	Mean Height feet	Volume cub. feet
1	15		62	16	1800
2	17		60	14	1400
3	18		61	13	1100
4	21		84	20	1700
5	27	1400	130	33	3300
6	29	2400	99	25	2050
7	34	1480	133	35	3250
8	35	1670	113	32	2800
9	35	910	156	46	4450
10	46	620	165	55	4800
11	47	740	150	47	4230
12	48	860	132	40	2900
13	49	680	154	52	4700
14	50	750	132	44	3500
15	54	450	182	69	6400
16	62	450	169	65	4700
17	62	369	184	73	6200
18	68	420	148	56	4450
19	74	270	192	83	7800
20	74	350	146	61	4000
21	76	295	173	70	5500
22	79	265	177	72	6300
23	81	245	192	86	7200

n.b. In practice a much greater number of plots would be required.

The graph (*Fig.* 33) is prepared from the above table and the plots allotted to quality classes as follows :—

I Quality. Plots 1, 5, 9, 10, 15, 17, 19, and 23.
II Quality. Plots 2, 4, 7, 8, 11, 13, 16, 21, and 22.
III Quality. Plots 3, 6, 12, 14, 18, and 20.

The volumes for entry in the yield table given below are obtained from the mean volume curve (dotted line in *Fig.* 33). The other information required for the yield table is obtained from graphs as already stated; thus for mean height in quality class I the figures to be graphed will be as follows :—

Plot	Abscissa Age	Ordinate Heights
1	15	16
5	27	33
9	35	46
10	46	55
15	54	69
17	62	73
19	74	83
23	81	86

Part of the yield table prepared from the several graphs is shown below :—

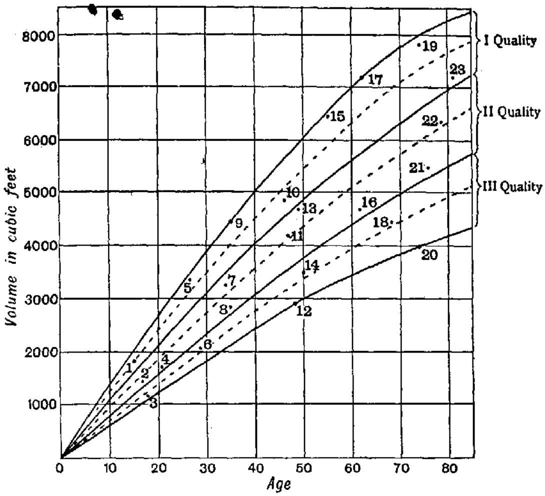


FIG. 33. Strip volume method of assessing the quality of woods.

Yield Table for Scots Pine I Quality.

Age	Number of trees	s.b.h. sq. ft.	Mean height feet	Volume cubic feet
10		30	9	1,000
20		92	22	2,100
30	1,200	133	38	3,250
40	770	160	52	4,400
50	520	175	64	5,400
60	370	184	73	6,250
70	290	190	80	6,950
80	250	192	85	7,600

3. Strip Height Method

This method was suggested by Schlich (1) when criticising the B.F.C. method (described next). It is a modification of Baur's method in which mean heights instead of volumes are used for the purposes of classification, which is carried out as shown in *Fig*. 33. The remainder of the procedure is the same as Baur's except that separate age-volume graphs must be prepared for each quality class after the plots have been allotted to it by their mean heights. For woods which have not been uniformly treated in the past the classification by height is preferable to that by volume.

4. British Forestry Commission Method (10)

(a) Scope of the Tables. — The tables are general ones for Great Britain for the following species, Scots and Corsican Pine, European and Japanese Larch, Norway and Sitka Spruce and Douglas Fir. In the case of Scots Pine separate tables are prepared for Scotland.

(b) Selection of Plots.—The first step is to select sample plots on all types of locality and of all ages well spread over the whole area.

(c) Measurement of Plots. — After making any thinning required, the plots are measured up in a manner fully described in B.F.C. Bulletin No. 10. In each plot three sample trees, having approximately the mean height of the crop, are selected, and these trees are submitted to stem analysis for the purpose of quality class classification as explained below.

(d) Classification into Quality Classes. — Height is the basis of classification, the B.F.C. objecting to classification by volume, in the case of British woods, for the reasons already given on p. 89. The B.F.C. reject Baur's strip method of classification, either by height or volume, on the ground that the whole trend of the curves is based on what is inevitably the scantiest part of the data, namely, the fastest and slowest growing woods. They select the mean height of the plots at the age of 50 years as the quality indicator. They consider 50 years a suitable age in the case of coniferous woods because by that time most of the factors of locality may be expected to have found expression in the growth of the crop, and the choice of a higher age would unduly restrict the material available. The procedure in classification is as follows:—

(i) From the stem analyses, carried out—see (C) above—in such plots as are 50 years of age and over, mean height curves for each plot throughout its life are prepared, *Fig.* 34, and the range of height *at* 50 *years* is observed and divided into 10 feet divisions representing quality classes, thus

40 foot class lies between the limits of 35 and 45 ft.
50 foot class lies between the limits of 45 and 55 ft.
60 foot class lies between the limits of 55 and 65 ft.

The number of quality classes for each species depends then on the range of height at 50 years. For example, there are 5 classes for Norway Spruce ranging from 40 to 80 feet, but only 3 for Corsican Pine ranging from 50 to 70 feet.

(ii) On the basis of their height at 50 years the plots of this age and over are then tabulated in quality classes, as follows, this example being for Quality III Larch equivalent to the 50 foot height class.

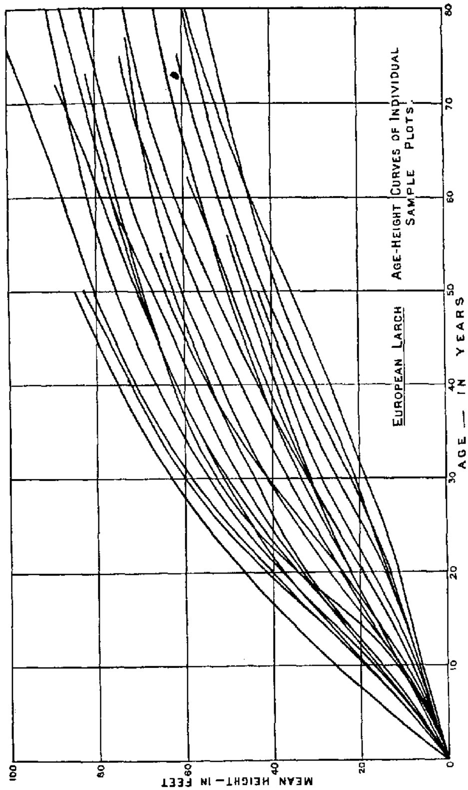
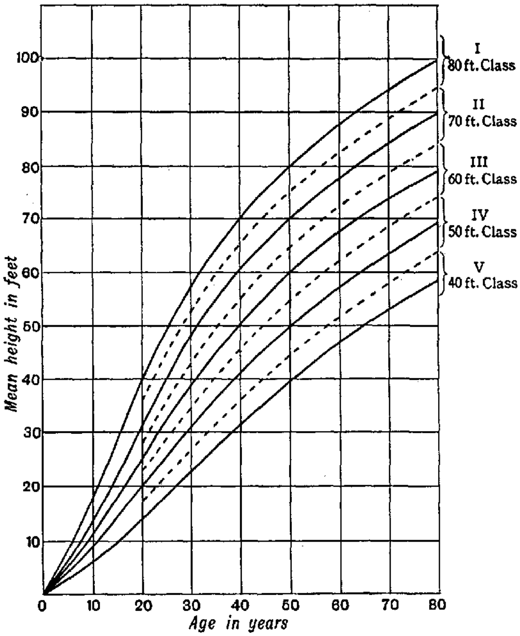


FIG. 34.

B.F.C. Bulliten No. 10

Plot No.	Height at 10 yrs.	20 yrs.	30 yrs.	40 yrs.	50 yrs.	60 yrs.	70 yrs.	80 yrs.	90 yrs.	100 yrs.
362	10	26	37	46½	56½	67				
352	5½	14	27½	43½	57	66				
	etc.	etc.	etc.	etc.	etc.	etc.	etc.			
Total height	725½	1631½	2411½	3072	1795½	1203½	878½	394½	82½	
No. of readings.	60	60	60	60	30	18	12	5	1	
Arithmetical mean height.	12	27	40	51	60	67	73	79	82½	



B.F.C. Bulletin No 10

FIG. 35. Strip height method of assessing the quality of woods. (European larch. B.F.C.)

(iii) The arithmetical mean heights obtained as above for each quality class are then plotted over ages as in *Fig.* 35, and the limiting curves (pecked lines) of the quality classes interpolated.

(iv) Plots less than 50 years old can now be allotted to their respective quality classes by the position given them by their mean height on this graph.

(e) Construction of the Yield Tables.—Graphical methods are employed as in Baur's method; but, since mean height at a given age has been used as the criterion in the case of quality classes, it is used again as a basis in the study of the volume, basal area, number of stems and girth. Thus graphs are prepared from the data for each plot in which the volumes, etc., are plotted against the mean heights and mean curves are drawn, these being used in preparing the table given below.

The form factors are obtained by calculation at each 5 year period using the usual formula $f = \frac{V}{h \times s.b.h.}$; the figures obtained are then graphed by age.

Table illustrating Method of presenting the Data.
European Larch—Quality Class II (70 ft.).

1 Age in years	2 Mean height in feet	3 Mean quarter girth at 4ft. 3in.	4 No, of stems per acre	5 Basal area Sq. ft. per acre	6 Form Factor	7 Volume Cubic feet under Bark per acre
10	14	—	—	—	—	—
15	23	—	—	—	—	—
20	31½	3¼	1,160	82	·348	900
25	40	4¼	850	99	·384	1,520
30	48	5	640	113	·387	2,100
35	55	6	500	123	·384	2,600
40	61	6¾	410	131	·382	3,050
45	66	7½	350	137	·377	3,410
50	70	8¼	310	141	·375	3,700

NOTE.—Column 2 is filled in from the age-height graph (*Fig.* 35) and, for these heights, the remaining columns are filled in from the corresponding graphs.

The British yield tables also give the yield from thinnings. The number of stems removed at each thinning is obtained directly from comparing the number of stems in the main crop at different ages. Data not being available to determine the volumes, they are derived from a theoretical consideration of the ratios existing between the mean volume per stem of the main crop and that of the thinnings, the ratios being based on continental yield tables.

(f) Merits of the Method.— The method is one of great theoretical exactness. Reference to the full account of the method in Bulletin No. 10 shows that difficulties have arisen in practice at various stages of the work, and considerable "adjustments" have had to be made in drawing the graphs. This suggests the possibility that a simpler, if less theoretically

accurate method, might yield equally useful results. Height is a good basis for classification of quality classes, and probably the only possible basis in the case of existing British woods; but with a simple substitution of mean heights for volumes in the initial classification of quality classes, Baur's method could be applied to British woodlands and would result in a great simplification of the procedure. The reasons for objecting to it, which have already been given, are sound in theory, but, in view of the somewhat unsatisfactory material from which the yield tables are necessarily derived, it would possibly produce data of not less practical value. Moreover, the condition of British woodlands at the time of the preparation of these yield tables must be considered as ephemeral; and the existing yield tables can therefore only be regarded as temporary. When the more efficient management now being applied has had time to take effect, doubtless revised yield tables will be prepared. Actually the British tables are based on a much greater number of samples than are most of the Continental ones, but they also cover a much wider range of conditions than the latter.

Wherever yield tables have to be prepared for forests which have not been long under scientific management, height rather than volume will probably have to be made the basis of quality classes. This applies to most forests in the British Empire, and the above remarks are made not with the object of criticising the B.F.C. method, but with a view to suggesting that simplifications of the method are possible in these countries where the staff available for the work is very limited.

E. APPLICATION OF YIELD TABLES TO DETERMINE QUALITY OF LOCALITY

An examination of any set of yield tables prepared from normal woods will show that, at any age, the volume, height, mean girth and total basal area rise with an improvement in the quality class, whereas the number of stems falls. In theory, therefore, any of these factors may be made the basis for determining quality and in practice they may all be taken into consideration. Actually, however, height is the factor which is principally relied upon in assessing quality, even where, as in Baur's method, the classification of the tables is by volume. The reason is, as has already been stated, that height is the factor least affected by the departures from normal which are common in all woods; moreover, the determination of height is a more simple process than the determination of volume. The height of the wood to be classified must, of course, be determined by the same method as has been used to determine the heights given in the yield tables. Having determined, either by ring

countings or from records, the age of the wood to be classified, it is assigned to that quality class with which its measurements most closely conform at the same age. If the age does not concide with one of the yield table age intervals, the data in the table must be graphed, unless the original graphs from which the table was prepared are available. If the volume or number of trees per acre are to be used in the classification, it will have to be considered whether the plot measured in the wood to be classified is fully stocked and, if it is not, its figures will have to be raised accordingly before a comparison with those in the yield table is made. Thus, if the density is 0·8, the volume or number of trees must be multiplied by $\frac{10}{8}$. There is *no statistical basis* which can be relied upon for the classification of very young woods. Comparison may be made with an older wood growing locally in a similar locality; failing this, only an estimate, based on a study of the soil and ecology, can be made.*

F. APPLICATION OF YIELD TABLES TO DETERMINE THE VOLUME AND INCREMENT OF A WOOD

The first step is to determine the quality—as explained above—in order to know what table to apply. If the wood is fully stocked, the increment per acre can be read directly from the table; or from the yield table graphs, if the ages do not coincide.

In most cases, however, the wood will not be fully stocked and its density, in comparison with the figures for a fully stocked acre given by the table, will have to be assessed. There are four methods of assessing the density of a wood.

(a) *By eye.*
Only to be undertaken by an experienced estimator.
(b) *By volume.*
(c) *By the number of trees.*
(d) *By total basal area.*

In any of the last three cases one or more sample plots will be laid out and the necessary measurements or countings made.

Of these three methods (d) is the best, (b) being inconvenient—if used, the use of the yield table to determine volume is

* It is a common practice to use the mean height of the crop as the quality indicator (See B.F.C. method). This is open to criticism since the mean height of the crop is a factor which may be considerably affected by the method of making thinnings. The mean height of the dominant trees is likely to be a much more reliable indicator, since it is unlikely to be materially affected by any treatment, unless the latter is so inefficient as to cause a deterioration of the soil—and stability of the conditions of the locality is postulated when yield tables are employed. In his yield tables for teak in India (13) Mr. R. Bourne gives strong reasons for considering the height of dominant trees only in classifying quality classes.

dispensed with—and (c) unreliable. Using methods (a), (c) or (d) the volume of the wood may be assumed to be in proportion to the density; thus, if the yield table figure for basal area is 100 square feet and that for the sample plot 80 square feet per acre, the yield table volume must be multiplied by the *reducing factor* $\frac{80}{100}$ to obtain the volume of the wood per acre.

There are two conditions which must be considered in calculating the future increment.

1. *The increment is in proportion to the density.* This may be approximately the case where the increment for a very few years in the future is required, or where the proportionately low density does not represent general under-stocking but is caused by the presence of blanks. The increment is then calculated in the same manner as the volume.

2. *The increment is not in proportion to the density.* This is much more usually the case, since the more open nature of the wood will allow of an increment proportionately greater than that in a fully stocked wood, so that
actual increment $>$ yield table increment $\times$ reducing factor.

The question of the relation between density and future increment has been studied by Professor E. Gehrhardt in Germany* and he gives the two following formulæ, arrived at experimentally, for determining the latter.

$Zr = bZ\ (2 - b)$ for shade-bearing species.
$Zr = bZ\ (1{\cdot}7 - 0{\cdot}7b)$ for light-demanding species.
where Zr = increment required of the understocked wood.
Z = corresponding increment from the yield table.
b = ratio of actual to normal basal area (*i.e.* reducing factor).

Gehrhardt's formula has been found by S. R. Gevarkiantz† to apply to certain species in America.

The application of yield tables to determine the volume and increment of whole woods and forests is dealt with in the next chapter.

G. LAYING OUT A PERMANENT SAMPLE PLOT

In the first place it may be mentioned that, though the reference in this chapter is to sample plots in even-aged woods used for the purpose of constructing yield tables, they may be laid out in and used for studying growth in uneven-aged woods.

* Yield tables for pure even-aged woods of Oak, Beech, Silver Fir, Scots Pine, Green Douglas and Larch.

† The approach of Northern Hardwood Stands to Normality. S. R. Gevarkiantz. Journal of Forestry (U.S.A.), May, 1937.

The plot must be fully stocked and normal, that is to say the best obtainable sample of a wood resulting from the accepted treatment on the locality in question. Its dimensions in any direction must not be less than a certain minimum which, as stated on p. 87, will depend on the size of the trees at the maximum age up to which it is intended to continue the measurements. Further, allowance must be made for a " surround," an area of wood surrounding the plot which has a similar type of growth and which will be treated in the same manner. Its object is to ensure that the edge of the wood grows under the same conditions as the inside and to provide material for sample trees when these have to be felled and cannot be cut in the plot itself. If the results of different treatments, *e.g.* different grades of thinning, are to be tested, the plot must be large enough to be divided into two or more parts; it is, moreover, desirable that there should be a " surround " between each of these sub-plots. For convenience the plots are generally made rectangular in shape and the corners are marked with pillars or posts. The sides should be demarcated; a convenient method is to mark with paint on the sides facing the plot the trees in the surround which lie along its edge. After any required thinnings have been made and the particulars of the same noted, the remaining trees are numbered and measured. The numbers are generally painted on the bark of the trees; as an additional precaution the position of each tree is sometimes fixed by offsets on a large scale plan. The height where the diameter or girth of each tree is measured should be marked with paint, so that remeasurement may be made at the same place. The crop is measured by one of the methods given in Chapter VII.

In the record of sample plots it is customary to enter the following information:—

(a) Geographical situation.
(b) Conditions of locality such as :—aspect, slope, exposure, underlying rock and soil.
(c) Remarks on undergrowth, ground vegetation and soil covering,

and at each measurement :—

(d) Age.
(e) Mean height.
(f) Mean girth or diameter.
(g) Number of stems.
(h) Basal area.
(i) Volume.

} This information is required for the trees removed in thinnings as well as for the main crop

(j) Bark percentage.
(k) Crown percentage.

The **Crown Percentage** is the average of the upper and lower crown, expressed as a percentage of the total stem length; it is obtained from the formula,

$$\text{Crown percentage} = \frac{L - \frac{U.C + L.C.}{2}}{L} \times 100$$

where L = the total length of the stem and U.C. and L.C. = the length of the upper and lower crown respectively.

It is generally obtained from the sample trees. Since the development of the stem depends mainly on the amount of green leaf surface, a knowledge of the crown percentage may be of value in comparing different plots and methods of treatment.

CHAPTER IX

THE MEASUREMENT OF FORESTS

BY R. BOURNE

Forestry, being a long term investment, demands more than any other productive business that the working should be planned. Sound planning is impossible without a knowledge of the relevant facts as to:—

A. The productive capacity of the several sites occurring in a forest.
B. The growing stock present in the forest, and
C. The nature and dimensions of the material for which a demand is anticipated.

The determination of the relevant facts under (A) and (B) is termed *stock-taking* and the technique employed in this process is likely to be influenced by those determined under (C). Stock-taking is an essential preliminary to the preparation of *Working Plans* (14).

A. PRODUCTIVE CAPACITY OF SITES

Reference has been made in the last chapter to the fact that assessment of *site quality* has generally been based in the past on statistics of production. *Statistical assessment* relates to the quantity, whether measured in terms of volume or height growth, which a site is capable of producing under a defined treatment and in a given time. Mention has also been made of an alternative and wider basis—*ecological assessment*—which takes into account not only statistics of production but also the *local factors*, climate and soil, which influence the production and, together with the forest canopy, largely control the associated *ground vegetation*.

(a) STATISTICAL ASSESSMENT OF SITE-QUALITY

The volume or height-growth of a crop on a given site varies not only with the age but also with its past treatment. Therefore, for the determination of the site-quality on a statistical basis, it is necessary to know both the age and the past treatment.

If yield tables, applicable to the crop or forest in question, are available, the usual procedure is as follows :—

(i) Ascertain from the yield table, for the ages of the crops to be assessed, the limits between quality-classes in terms of average dominant height.

EXAMPLE :—

B.F.C. Bulletin No. 10, pp. 43 & 44.*

Yield Table for European Larch.

	Quality Classes. Mean dominant heights at 50 years								
	80ft.		70ft.		60ft.		50ft.		40ft.
Height at 30 yrs.	58′		48′		39½′		31½′		?
Heights limiting Quality-classes		53′		43¾′		35½′		?	
Height at 50 yrs.	80′		70′		60′		50′		40′
Heights limiting Quality-classes		75′		65′		55′		45′	

(ii) Prepare a tracing from a map, on a scale of at least 6 inches = one mile, of the Larch areas likely to be assessed in a day's work and select an hypsometer suitable for the measurements of the heights concerned.

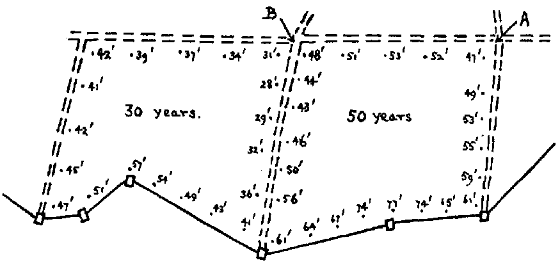


FIG. 36. Statistical assessment of site quality. Preliminary survey.

Forest Boundary.

Ride and Crop Boundary.

* See Chapter VIII for an explanation of the B.F.C. method. It is assumed, for the purpose of this example, that the mean heights are those of dominant trees only, as the author considers this condition essential. (See footnote to p. 97.) Actually the B.F.C. figures relate to the mean height of the crop.

(iii) Starting from a known point A (*Fig.* 36) proceed clockwise round the perimeter of the first crop to be assessed, say 50 years of age, measuring the heights of dominant trees at intervals of 2-3 chains and plotting the approximate positions of the trees and their heights on the map.

Starting from a known point B (*Fig.* 36) in the adjoining Larch crop, say 30 years of age, measure heights round the perimeter as before. These two sets of measurements indicate approximately the points at which the various quality-class boundaries cross the two crop boundaries.

(iv) In the light of the above information and in consideration of the fall of the ground and the probable quality-class

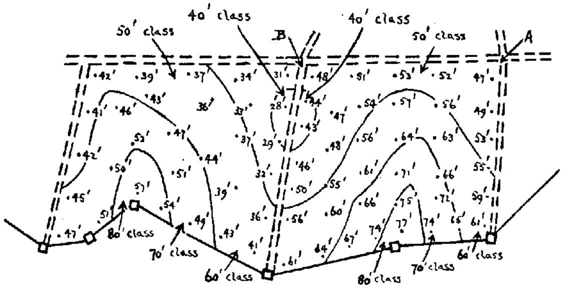


FIG. 37. Statistical assessment of site quality. Final map.

Forest Boundary.

Ride and Crop Boundary.

Quality Class Boundary.

differences, traverse the two crops plotting the approximate positions of the trees measured and their heights on the map. (*Fig.* 37).

In the 50 year old crop the height measurements which have been plotted indicate that the area was traversed in lines. In the event of such a procedure being adopted, the quality-class boundaries can only be interpolated approximately on completion of the height measurements. The use of line traverses is generally necessary where there are few or no topographic features, such as streams, ridges, etc., marked on the map and identifiable on the ground, from which the forester can constantly check his position when taking measurements within a crop.

In the 30 year old crop the height measurements which have been plotted indicate that the principle of bracketing has been applied. Starting in turn from the points at which quality-class boundaries cross the crop boundary, the heights of trees have been measured and plotted at intervals, first on one side and then on the other of the several quality-class boundaries, the positions of which were judged by the forester, as he proceeded, from his visual estimates of the tree heights.

By adopting this latter procedure the quality-class boundaries can be plotted by the forester on the map while actually on the ground. This method is, therefore, preferable to line traversing, but is only practicable where there are numerous local features from which the forester can constantly check his position on the map.

(v) Having plotted the quality-class boundaries, the forester proceeds to take out the area of each class, crop by crop, by means of a planimeter or with squared paper and to calculate the growing stock, increment, etc., for each class, either from sample plots or from the yield tables, as explained in the previous chapter.

It will be readily understood that, where crops of different species occur in a forest, the distribution of crops by species must be determined and the relevant yield tables employed in each case. Where mixed crops of two or more species occur, the statistical assessment of sites-quality is usually based on the most important or the most frequent species in the mixture.

If yield tables are not available, it is clearly impossible to delimit the boundaries of site-qualities on a statistical basis. By measuring and plotting the heights of dominant trees, however, it is possible, without actually drawing quality-class boundaries, to indicate the relative productivity of the various parts of a crop and to compare the growth of different crops of the same age. But, in the absence of growth curves on which yield tables are based, it is impossible to compare the growth with any statistical accuracy in crops of different age.

Obviously the foregoing remarks apply primarily to forests of even-aged crops. Yield tables are not applicable to uneven-aged woods. But in the latter, by measuring and plotting the heights of truly mature trees, to be judged by their crown form, it is again possible to indicate the relative productivity of the various parts of the crop and, moreover, to compare the growth of different crops.

(b) Ecological Assessment of Site-quality

Two sites of the same productive capacity, measured in terms of height or volume growth, may be very different from an

ecological standpoint and, indeed, may yield very different returns if the timber is measured in terms of value. The student of physiology and silviculture will have learnt that, with the majority of forest trees, the best growth in size generally results from an optimum combination of temperature, air and moisture in the soil, together with a sheltered position. Growth in size falls off if conditions tend to become extreme as to any one or any combination of these factors. For example, low productivity for a species is as often associated with cold wet soils as with warm dry soils, even in sheltered situations, while the effect of a favourable soil may be counteracted by exposure. Thus a purely statistical assessment of crop and site-quality often fails to distinguish between crops requiring very different treatment. Again the student of wood structure and utilisation will have learnt that some of the properties of wood and several of the defects which occur in it, all of which affect its quality and value, may be largely determined by actual site conditions. Large volume production does not necessarily imply high value. Growth can be much too fast for good quality. On the other hand, slow growth may be too slow or associated with some defect such as shake which greatly reduces the value of the timber. Indeed, a statistical assessment of site-quality, if looked upon as the primary assessment, often fails in many respects to meet the requirements of good forestry.

Ecological assessment of site-quality should undoubtedly constitute the primary assessment in any forest, a statistical assessment being superimposed upon it. That ecological assessments have been the exception rather than the rule up till quite recent times is due in part to the fact that ecology and pedology have only been developed as sciences since the beginning of the present century and in part to difficulties in the application of these sciences without a thorough knowledge of their principles. It is clearly beyond the scope of this book to expound these principles, but it is possible briefly to outline the procedure to be followed in the ecological assessment of site-qualities in any forest.

Preliminary Investigations

(i) The first step is to study the physiography and geological structure of the area. All rock exposures should be examined and the lithological character of the crops studied. If the rocks are stratified the various strikes and dips should be noted.

(ii) In the light of the knowledge so accumulated two or more linear traverses should be run across the area, levels and slopes being recorded, and soil and geological profiles exposed in pits at short intervals. The number and directions of these lines

should be such as to ensure that every site, or unit combination of climate, slope and geology which apparently occurs in the forest and immediate neighbourhood is traversed.

(iii) Sections in elevation should then be plotted from the data collected along each traverse and an attempt made to list the sequence* or sequences in which the several sites occur or recur. In any area of complex geology or pronounced topography, these sections will generally illustrate the division of the forest area into distinct sequences of sites and help the forester to visualise and understand the structure of the several unit regions into which the forest extends.

(iv) The last step is to study the geological, physiographical and general history of the area. The object in view should be the determination of the relative ages of the several sites as to their formation and of the relative periods during which various areas, sites or groups of sites, have remained undisturbed either as to ploughing, etc., of the soil or clearing of the vegetation.

Until a forester, or for that matter an ecologist or pedologist, has established a regional and historical background for a locality he cannot expect to carry out an ecological assessment of site qualities with any pretension to accuracy.

The sculpture of a land surface is the result of processes through many ages. Some parts may have been finished in prehistoric time; others may be changing even at the present. For instance, many plateaux in Great Britain are relics of a land surface of glacial age. On the other hand, flood plains are of very recent alluvial origin, while some slopes are constantly subject to erosion. Thus the soils on some sites may have been subject to processes associated with past climatic eras and, if they have never been ploughed, their profiles may still show the effect of such climates and the vegetation on them be peculiar, at least in some respects. Such soils are termed *fossil soils*. On younger sites which have been formed within the present climatic era, the soil profiles and the associated ground vegetation may be quite distinct in ploughed and unploughed examples. Again, the ground vegetation may have been materially affected by recent changes in land utilisation. Finally, within a forest, differences in the tree crops, as to species, age and density, may have a profound effect on the ground vegetation.

In all these circumstances, soil and vegetation surveys, which are carried out without first establishing a correct regional and historical background, are liable to present great difficulties and reveal many apparent inconsistencies. For these reasons many attempts in the past, and even at present, to carry out site assessments on an ecological basis have proved abortive. If, however,

* Such a sequence has been termed a "catena" by pedologists.

a correct scientific background is first established, following the procedures outlined above, a classification of forest types and the recognition of the several guises in which each type may appear should present little difficulty to a fully qualified forester.

(c) Classification of Forest Types

(i) The first step should be an approximate delimitation of site boundaries, recording at the same time the local history, so far as it is known or can be deduced from surface phenomena, the frequency and constancy of species in the ground vegetation, and the height for age and the density of the tree canopy. Experience has shown that perennial plants are much more typical of a site-type than annuals, and, in consequence, such a survey is best carried out in the early spring months. From a silvicultural point of view, particularly in the matter of regeneration, it is important to re-examine the area in the height of summer to determine the density of the annuals as an indication of the danger of weed growth.

(ii) From the data collected above, it is essential to distinguish all the examples which occur of sites on which the soil profiles are relatively mature (also the fossil profiles) and the ground vegetation is well developed. The latter is to be expected in old woods both historically and as to age or height of the canopy. Care must be taken to see whether every site-type is represented among these examples, because, for historical reasons, no old woods may occur on some sites. In that event the older examples which do occur must be picked out for comparison and a special note made as to the relative ages of the soils. Detailed comparisons of the soil profiles and ground vegetation should then be made on all the examples selected. From these comparisons it should be possible to recognise and define, at least in general terms, the mature forms of several forest types.

(iii) The next step is to pick out all the immature examples of each type and to grade them as far as possible in descending order as to age. For instance, the mature (relative) form of a type in an old Beech crop may be a dense but low carpet of brambles (Rubus spp) with a few acid tolerant herbs and grasses. In a middle-aged Beech crop on another example of the same site, the form of the type may be a thin carpet of brambles with a higher frequency of the acid tolerant herbs and grasses and a few acid tolerant mosses. On the other hand, in a dense young Beech wood on a further example of the same site, the ground may be clean but for colonies of acid tolerant mosses and, in spring, of wood sorrel (Oxalis acetosella). If Oak woods of different ages occur in the same forest and on the same site-type, the brambles would be more rampant and the herbs and grasses

more frequent under an old oak canopy than under the old Beech, while, in the immature Oak woods, the brambles would appear and the ground vegetation develop at relatively earlier ages than in the Beech woods.

(iv) The final step is to study, for each site-type, the development of the vegetation in open old woods on the one hand and in adjacent waste lands, if they occur, on the other. In this manner, the ecological succession of each forest type can be traced and the various stages in the development of the vegetation on each be defined.

In the circumstances it should be realised that the site-map illustrates the distribution of the several forest types irrespective of the crops or the stages reached in their development. But the descriptions made of each crop and the associated ground vegetation and the statistical data collected as to height may be plotted in graphical form on the site map and will indicate the many crop differences within each forest type. From such a map the relative productivity of each site will be apparent. Moreover, the growth of different species on each site may be directly compared; no confusion should arise from the fact that very different types are often of similar productivity; and the best silvicultural treatment of each species from early youth to maturity, including its regeneration, can be determined site by site. Thus it may be repeated that an ecological assessment of site-quality is much to be preferred to a statistical assessment as the basis of stock-taking. It can be applied to both regular and irregular crops, and, if correct procedures are employed, there is no reason why it should not be of general application.

B. GROWING STOCK

If a statistical assessment of site-quality has been employed and yield tables are available, calculation of the growing stock simply involves a knowledge of the use of such tables (See pp. 96-98). But, if yield tables are not available or an ecological assessment has been made, volume measurements are necessary.

The selection of the crops to be measured is influenced mainly by the intensity of the management. In intensively managed, irregular forests complete enumeration or 100 per cent. measurement of the trees is sometimes made. In practice, measurement of the trees below a certain diameter or girth breast-height is omitted. The trees are generally re-measured at intervals in order to determine the periodical increment and, for this reason, it is desirable that breast-height should be marked on each tree to ensure that the measurements taken at intervals are reasonably comparable. The enumerations are usually kept separate for each compartment, but experience has shown that

this is unsatisfactory when more than one forest type occurs within a compartment. Since remeasurement for purposes of determining increment is nothing but the application of the principles of statistical research on a field scale, it is obvious that the first principle of such research in forestry—the elimination of site variations—must not be ignored. Clearly, the correct procedure involves an ecological assessment and delimitation of the site-qualities in such a forest and the closing of enumerations not only crop by crop, but also site by site.

In general, however, it may be said that complete enumeration is an unnecessary expense(!)Given an ecological assessment of site-quality it is easy to select true samples and only necessary to measure the volume on a comparatively small number of sample plots. This applies both to even-aged and uneven-aged woods. Having determined the crops of which it is necessary to have sample measurements, the forester has to decide the location and size of the plots.

Since the determination of periodical increments is all-important in forest management, it is a short-sighted policy not to provide for the remeasurement of sample plots at reasonable intervals of say 10-12 years. Experience has shown that shorter intervals are undesirable owing to the annual variations in growth within the sun-spot cycle. If these points are accepted, it follows that the plots must be demarcated and any fellings made in them, in the interval between measurements, recorded. Remembering that they must not extend over more than one site-type, it is obvious that the plots should be laid out to permit of easy demarcation and should not be so small as to be in danger of being overlooked when the ordinary fellings are carried out in the crops they represent. Apart from these considerations no definite rules need be laid down; the matter is one to be left to the good judgment of the forester concerned.

Again, with a view to the determination of increment it is desirable in the actual volume calculation to measure all the trees in the plot and employ volume tables. Such tables may introduce errors into the volume calculation but, since similar errors are involved at each remeasurement, the consequent errors in the determination of the increment are systematised and so minimised. Since volume tables are easy to prepare, if they are not available, immediate steps should be taken to compile them.

In circumstances in which a preliminary and rough estimate only is required of the stock in a forest, staff and funds may often be lacking with which to carry out either a statistical or ecological assessment of site-qualities. In that event no map can be prepared to illustrate the many differences in stocking which may occur in the forest, and it is, therefore, difficult and unwise to

rely on selected sample plots for the determination of the volume. The forester has no guide by which to select the plots and cannot be sure that they are reasonable samples. Under these conditions, experience has shown that sample plots in the form of linear or strip surveys give the best results, more especially if the lines are run more or less at right angles to the drainage systems, primary and secondary. Laid out in this manner the lines run from ridge to valley or at least from dry to relatively wet ground and tend to sample the several sites at any rate, roughly in proportion to their distribution, though for historical reasons this may not hold true in respect of the forest crops.

The percentage of the forest enumerated depends upon the width and distance apart of the strips. The broader the strips the further apart need they be to cover the same percentage of the forest area. At the same time, the more strips there are the more likely are they to traverse the several sites and types in proportion to the site and type distribution. On the other hand, many narrow strips involve more work and expense than fewer but broader strips. In practice it is usual to make the strips one chain (66 feet) broad, half-a-chain on either side of the central line. In this way every 10 chains enumerated in horizontal projection represents 1 acre. Obviously, if measurements are made on a slope, a correction must be made to allow for the slope. This is generally effected by running a level along the central line, using a chain or tape having an additional length, termed the *trailer,* on which the extra distances to be measured on the slope for different angles or percentages of slope are marked.*

By making the strips only a chain wide, half-a-chain on either side of the central line, it is generally possible to judge by eye which trees are within 33 feet of the central line and have, therefore, to be measured. With broader strips it is necessary to run out a tape at right angles at intervals in order to determine the trees to be included or excluded from the measurement.

When recording the measurements it is usual to close the enumeration book at every 10 chains or at any obvious change of site or of crop. By this means it is possible to work out the average stocking acre by acre, or, at any subsequent time, to group the statistics as circumstances may suggest.

Since strip surveys are generally of a provisional nature, remeasurement is rarely in view and, therefore, there is no need to demarcate the boundaries. If, however, remeasurement is intended, demarcation is confined to marking the position of the central line. In that event care must be taken in any subsequent

For a detailed description of the procedure to be followed see "Abney Level Handbook." United States Government Printing Office, Washington (1927).

fellings in the area to record separately the trees felled in an enumerated strip. Otherwise the record will be vitiated and rendered useless for the determination of increment. In practice, when marking trees for the ordinary fellings it is difficult to recognise the enumerated strip unless the central line is very clearly demarcated or each measured tree is numbered or ringed with paint. Indeed, the difficulties and expense of demarcation render the use of strip surveys undesirable where re-enumeration is in view.

Finally, the actual volume calculations are made from volume tables, if available, or by felling and measuring a number of sample trees at intervals along the strips enumerated. An alternative is to estimate the volume of each tree when its diameter or girth is measured.

(C) MARKET REQUIREMENTS

For purposes of management it is insufficient to determine only the volume of the growing stock. It is essential to estimate the value at least of the trees or crops which are likely to be felled in the immediate future. With this end in view it is important to investigate the markets to which the timber may be sent and to ascertain the prices it is likely to realise. And, in order that the valuations may be carried out in the field, at the time the growing stock is being measured, it is necessary to carry through these enquiries at an early stage in the stock-taking.

The most important consideration is the grading of the logs, poles, etc., actually in force in the several markets in question. Grading rules should be drawn up by which the enumerator, making due allowances for defects, can classify the trees at the time they are measured. An estimate is thereby made not only of the volumes but of the standing values. The actual procedures to be followed are subjects for consideration in studying forest utilisation and only the importance of such valuations for purposes of management has been stressed here. Stock-taking, to be efficient, must be comprehensive and the utilisation aspect of it is far from being the least important.

APPENDIX I

BARK PERCENTAGES

(Sample figures taken from the tables given by J. Macdonald in *Forestry*, Volume VII, 1933)

g.o.b. at breast height	Bark percentages at different points on the stem									
	Breast Height	Percentage of stem length between breast height and tip of tree								
		10	20	30	40	50	60	70	80	90
					Scots Pine.					
12	11·60	8·20	6·80	6·35	6·45	6·70	7·10	7·85	9·60	12·53
24	11·50	8·00	6·25	5·50	5·30	5·40	5·65	6·25	8·05	11·45
44	11·45	7·55	5·05	4·30	3·95	3·75	3·70	3·90	4·50	8·50
					Norway Spruce.					
12	6·50	6·00	6·00	6·10	6·30	6·65	7·75	9·55	11·80	16·20
20	5·55	5·35	5·35	5·45	5·65	5·95	6·50	7·70	10·15	14·60
32	4·45	4·25	4·30	4·40	4·65	5·00	5·60	6·65	8·25	12·70
					Douglas Fir.					
12	7·35	7·00	6·80	6·70	6·75	6·95	7·45	8·60	11·70	17·70
40	7·20	6·20	5·75	5·60	5·50	5·55	5·60	5·85	7·05	9·90
80	6·55	5·90	5·50	5·35	5·25	5·25	5·30	5·50	6·20	7·50
					European Larch.					
12	11·05	10·55	10·40	10·40	10·50	10·65	10·95	12·05	16·20	23·50
24	10·35	10·10	9·95	9·90	9·90	10·05	10·15	10·50	11·55	14·45
44	8·65	8·45	8·50	8·65	8·75	8·90	9·05	9·20	9·90	12·75
					Sitka Spruce.					
12	6·35	6·20	6·10	6·25	6·65	7·25	8·35	10·35	13·95	19·30
36	4·45	4·10	4·10	4·15	4·30	4·45	4·70	5·35	6·60	10·80
56	3·45	3·35	3·40	3·50	3·70	3·80	4·15	4·95	6·25	10·30
					Japanese Larch.					
12	9·25	9·10	8·95	8·95	9·15	9·55	10·35	11·65	13·75	21·80
20	8·30	8·20	8·20	8·30	8·55	8·90	9·45	10·15	11·85	18·75
28	6·40	6·70	7·05	7·40	7·65	7·90	8·15	8·55	9·75	14·40

NOTE.—It will be seen that, generally speaking, the smaller the girth the greater the percentage of bark; mid-sections of certain thick barked, species, like the Scots Pine, have, however, a smaller percentage of bark than the butt sections.

APPENDIX II

MULTIPLYING FACTORS FOR QUARTER-GIRTH MEASUREMENT

To obtain the volume in q.g. measurement multiply the figures in the 2nd column by the length in feet, thus 16 ins. q.g. $\times$ 10 ft. long = 17 9 4

Quarter girth	Ft.	Ins.	Pts.	Quarter girth	Ft.	Ins.	Pts.	Quarter girth	Ft.	Ins.	Pts.
3	0	0	9	14	1	4	4	25	4	4	1
3¼	0	0	10	14¼	1	4	11	25¼	4	5	1
3½	0	1	0	14½	1	5	6	25½	4	6	2
3¾	0	1	2	14¾	1	6	1	25¾	4	7	3
4	0	1	4	15	1	6	9	26	4	8	4
4¼	0	1	6	15¼	1	7	4	26¼	4	9	5
4½	0	1	8	15½	1	8	0	26½	4	10	6
4¾	0	1	10	15¾	1	8	8	26¾	4	11	7
5	0	2	1	16	1	9	4	27	5	0	9
5¼	0	2	3	16¼	1	10	0	27¼	5	1	10
5½	0	2	6	16½	1	10	8	27½	5	3	0
5¾	0	2	9	16¾	1	11	4	27¾	5	4	2
6	0	3	0	17	2	0	1	28	5	5	4
6¼	0	3	3	17¼	2	0	9	28¼	5	6	6
6½	0	3	6	17½	2	1	6	28½	5	7	8
6¾	0	3	9	17¾	2	2	3	28¾	5	8	10
7	0	4	1	18	2	3	0	29	5	10	1
7¼	0	4	4	18¼	2	3	9	29¼	5	11	3
7½	0	4	8	18½	2	4	6	29½	6	0	6
7¾	0	5	0	18¾	2	5	3	29¾	6	1	9
8	0	5	4	19	2	6	1	30	6	3	0
8¼	0	5	8	19¼	2	6	10	30¼	6	4	3
8½	0	6	0	19½	2	7	8	30½	6	5	6
8¾	0	6	4	19¾	2	8	6	30¾	6	6	9
9	0	6	9	20	2	9	4	31	6	8	1
9¼	0	7	1	20¼	2	10	2	31¼	6	9	4
9½	0	7	6	20½	2	11	0	31½	6	10	8
9¾	0	7	11	20¾	2	11	10	31¾	7	0	0
10	0	8	4	21	3	0	9	32	7	1	4
10¼	0	8	9	21¼	3	1	7	32¼	7	2	8
10½	0	9	2	21½	3	2	6	32½	7	4	0
10¾	0	9	7	21¾	3	3	5	32¾	7	5	4
11	0	10	1	22	3	4	4	33	7	6	9
11¼	0	10	6	22¼	3	5	3	33¼	7	8	1
11½	0	11	0	22½	3	6	2	33½	7	9	6
11¾	0	11	6	22¾	3	7	1	33¾	7	10	11
12	1	0	0	23	3	8	1	34	8	0	4
12¼	1	0	6	23¼	3	9	0	34¼	8	1	9
12½	1	1	0	23½	3	10	0	34½	8	3	2
12¾	1	1	6	23¾	3	11	0	34¾	8	4	7
13	1	2	1	24	4	0	0	35	8	6	1
13¼	1	2	7	24¼	4	1	0	35¼	8	7	6
13½	1	3	2	24½	4	2	0	35½	8	9	0
13¾	1	3	9	24¾	4	3	0	35¾	8	10	6
								36	9	0	0

APPENDIX III

AREAS OF CIRCLES FOR DIAMETERS 1 in. to 60 ins. (SCHLICH)

Diam. in inches	Area of circle in square feet	Diam. in inches	Area of circle in square feet	Diam. in inches	Area of circle in square feet
1·0	·0055	4	·2234	8	·7595
1	·0067	5	·2304	9	·7724
2	·0079	6	·2376	12·0	·7854
3	·0092	7	·2448	1	·7986
4	·0107	8	·2522	2	·8118
5	·0123	9	·2597	3	·8252
6	·0140	7·0	·2673	4	·8387
7	·0158	1	·2750	5	·8523
8	·0177	2	·2828	6	·8660
9	·0197	3	·2907	7	·8798
2·0	·0218	4	·2987	8	·8937
1	·0240	5	·3068	9	·9077
2	·0264	6	·3151	13·0	·9218
3	·0289	7	·3234	1	·9360
4	·0314	8	·3319	2	·9504
5	·0341	9	·3404	3	·9648
6	·0369	8·0	·3491	4	·9794
7	·0398	1	·3579	5	·9941
8	·0428	2	·3668	6	1·0089
9	·0459	3	·3758	7	1·0237
3·0	·0491	4	·3849	8	1·0387
1	·0524	5	·3941	9	1·0538
2	·0559	6	·4034	14·0	1·0690
3	·0594	7	·4129	1	1·0843
4	·0631	8	·4224	2	1·0997
5	·0669	9	·4321	3	1·1153
6	·0707	9·0	·4418	4	1·1309
7	·0747	1	·4517	5	1·1467
8	·0788	2	·4617	6	1·1626
9	·0830	3	·4718	7	1·1785
4·0	·0873	4	·4820	8	1·1946
1	·0917	5	·4923	9	1·2108
2	·0963	6	·5027	15·0	1·2272
3	·1009	7	·5132	1	1·2437
4	·1056	8	·5238	2	1·2602
5	·1105	9	·5345	3	1·2768
6	·1154	10·0	·5454	4	1·2936
7	·1205	1	·5564	5	1·3104
8	·1257	2	·5675	6	1·3274
9	·1310	3	·5787	7	1·3444
5·0	·1364	4	·5900	8	1·3616
1	·1418	5	·6014	9	1·3789
2	·1474	6	·6129	16·0	1·3963
3	·1532	7	·6245	1	1·4138
4	·1590	8	·6362	2	1·4314
5	·1650	9	·6481	3	1·4492
6	·1710	11·0	·6600	4	1·4670
7	·1772	1	·6721	5	1·4849
8	·1835	2	·6842	6	1·5030
9	·1899	3	·6965	7	1·5212
6·0	·1963	4	·7089	8	1·5394
1	·2029	5	·7214	9	1·5578
2	·2096	6	·7340	17·0	1·5763
3	·2164	7	·7467	1	1·5949

Diam. in inches	Area of circle in square feet	Diam. in inches	Area of circle in square feet	Diam. in inches	Area of circle in square feet
2	1·6136	5	2·7611	8	4·2152
3	1·6324	6	2·7857	9	4·2456
4	1·6513	7	2·8104	28·0	4·2761
5	1·6703	8	2·8352	1	4·3067
6	1·6894	9	2·8602	2	4·3374
7	1·7087	23·0	2·8852	3	4·3682
8	1·7280	1	2·9103	4	4·3991
9	1·7475	2	2·9356	5	4·4301
18·0	1·7671	3	2·9610	6	4·4612
1	1·7868	4	2·9864	7	4·4925
2	1·8066	5	3·0120	8	4·5238
3	1·8265	6	3·0377	9	4·5553
4	1·8465	7	3·0635	29·0	4·5869
5	1·8666	8	3·0894	1	4·6186
6	1·8869	9	3·1154	2	4·6504
7	1·9072	24·0	3·1416	3	4·6823
8	1·9277	1	3·1679	4	4·7143
9	1·9482	2	3·1942	5	4·7464
19·0	1·9689	3	3·2207	6	4·7787
1	1·9897	4	3·2471	7	4·8110
2	2·0106	5	3·2748	8	4·8435
3	2·0316	6	3·3006	9	4·8760
4	2·0527	7	3·3275	30·0	4·9087
5	2·0739	8	3·3545	31	5·2414
6	2·0952	9	3·3816	32	5·5851
7	2·1167	25·0	3·4088	33	5·9396
8	2·1382	1	3·4361	34	6·3050
9	2·1599	2	3·4636	35	6·6813
20·0	2·1817	3	3·4911	36	7·0686
1	2·2036	4	3·5188	37	7·4667
2	2·2256	5	3·5465	38	7·8758
3	2·2477	6	3·5744	39	8·2958
4	2·2699	7	3·6024	40	8·7266
5	2·2922	8	3·6305	41	9·1684
6	2·3146	9	3·6587	42	9·6211
7	2·3371	26·0	3·6870	43	10·0847
8	2·3597	1	3·7154	44	10·5592
9	2·3825	2	3·7439	45	11·0447
21·0	2·4053	3	3·7725	46	11·5410
1	2·4283	4	3·8013	47	12·0482
2	2·4514	5	3·8301	48	12·5664
3	2·4745	6	3·8591	49	13·0954
4	2·4978	7	3·8882	50	13·6354
5	2·5212	8	3·9174	51	14·1863
6	2·5447	9	3·9467	52	14·7480
7	2·5684	27·0	3·9761	53	15·3207
8	2·5921	1	4·0056	54	15·9043
9	2·6159	2	4·0353	55	16·4988
22·0	2·6398	3	4·0650	56	17·1042
1	2·6638	4	4·0948	57	17·7206
2	2·6880	5	4·1248	58	18·3478
3	2·7122	6	4·1548	59	18·9859
4	2·7366	7	4·1850	60	19·6350

APPENDIX IV

AREAS OF CIRCLES FOR CIRCUMFERENCES FROM 3 in. to 144 ins.

Circumference in inches	Area sq. feet	Circumference in inches	Area sq. feet	Circumference in inches	Area sq. feet
3	·0050	51	1·4378	98	5·3091
4	·0088	52	1·4947	99	5·4178
5	·0138	53	1·5527	100	5·5278
6	·0199	54	1·6121	101	5·6389
7	·0271	55	1·6721	102	5·7510
8	·0354	56	1·7339	103	5·8644
9	·0448	57	1·7970	104	5·9789
10	·0553	58	1·8573	105	6·0944
11	·0669	59	1·9243	106	6·2118
12	·0796	60	1·9883	107	6·3291
13	·0934	61	2·0561	108	6·4483
14	·1084	62	2·1244	109	6·5680
15	·1243	63	2·1940	110	6·6886
16	·1415	64	2·2641	111	6·8094
17	·1598	65	2·3355	112	6·9357
18	·1790	66	2·4079	113	7·0582
19	·1996	67	2·4815	114	7·1879
20	·2211	68	2·5561	115	7·3107
21	·2438	69	2·6318	116	7·4293
22	·2675	70	2·7086	117	7·5670
23	·2924	71	2·7866	118	7·6970
24	·3183	72	2·8641	119	7·8282
25	·3455	73	2·9457	120	7·9533
26	·3737	74	3·0264	121	8·0931
27	·4030	75	3·1094	122	8·2244
28	·4335	76	3·1930	123	8·3630
29	·4643	77	3·2774	124	8·4977
30	·4971	78	3·3631	125	8·6371
31	·5311	79	3·4498	126	8·7759
32	·5660	80	3·5376	127	8·9156
33	·6020	81	3·6268	128	9·0565
34	·6390	82	3·7169	129	9·1973
35	·6772	83	3·8082	130	9·3420
36	·7160	84	3·9004	131	9·4862
37	·7566	85	3·9940	132	9·6316
38	·7982	86	4·0877	133	9·7785
39	·8408	87	4·1790	134	9·9258
40	·8844	88	4·2807	135	10·0755
41	·9292	89	4·3786	136	10·2245
42	·9751	90	4·4737	137	10·3741
43	1·0219	91	4·5776	138	10·5274
44	1·0702	92	4·6788	139	10·6800
45	1·1184	93	4·7799	140	10·8344
46	1·1697	94	4·8844	141	10·9900
47	1·2211	95	4·9891	142	11·1462
48	1·2733	96	5·0931	143	11·3032
49	1·3273	97	5·2011	144	11·4565
50	1·3819				

APPENDIX V

USEFUL TABLES

1 chain=22 yards: 1 inch=2·54 cm.: 1 yard=·9142 metres:
1 meter=39·37 inches, 3·28 feet, 1·094 yards:
1 acre=43,560 square feet, 4,840 square yards, 10 square chains, 0·40469 hectares:
1 hectare=2·47104 acres:
1 cord=128 cubic feet stacked:
1 cubic foot=0·0283 cubic meters:
1 cubic meter=35·3145 c. ft.:
1 cubic foot per acre=0·06997 cubic meters per hectare (0·08907 for quarter girth measurement):
1 cubic meter per hectare=14·2913 cubic feet per acre (11·2187 for quarter girth measurement).
1 cubic foot of water weighs 62½ lbs.:
Girth under bark=girth over bark−6·28×bark thickness.
Quarter girth under bark=quarter girth over bark−1·57×bark thickness.

EQUIVALENT DIAMETERS FOR QUARTER GIRTH

Multiplying factor 1·2732

Inches		Inches		Inches	
Quarter Girth	Diameter	Quarter Girth	Diameter	Quarter Girth	Diameter
4	5·09	15	19·10	26	33·10
5	6·37	16	20·37	27	34·38
6	7·64	17	21·64	28	35·65
7	8·91	18	22·92	29	36·92
8	10·19	19	24·19	30	38·20
9	11·46	20	25·46	31	39·47
10	12·73	21	26·73	32	40·74
11	14·00	22	28·00	33	42·02
12	15·28	23	29·28	34	43·29
13	16·55	24	30·56	35	44·56
14	17·82	25	31·83	36	45·84

NUMBER OF PLANTS OR TREES PER ACRE

Spacing in feet	Number	Spacing in feet	Number
2 × 2	10,890	12 × 12	302
2½ × 2½	6,970	13 × 13	258
2 × 3	7,260	14 × 14	222
2 × 4	5,445	15 × 15	194
3 × 3	4,840	16 × 16	170
3½ × 3½	3,556	17 × 17	151
3 × 4	3,630	18 × 18	134
3 × 5	2,904	19 × 19	121
4 × 4	2,722	20 × 20	109
4½ × 4½	2,151	21 × 21	99
4 × 5	2,178	22 × 22	90
4 × 6	1,815	23 × 23	82
5 × 5	1,742	24 × 24	76
5½ × 5½	1,440	25 × 25	70
6 × 6	1,210	26 × 26	65
7 × 7	892	27 × 27	60
8 × 8	680	28 × 28	56
9 × 9	538	29 × 29	52
10 × 10	436	30 × 30	48
11 × 11	300		

APPENDIX VI

TANGENTS OF ANGLES AND GRADIENTS

NOTE.—The slope per cent. = tangent × 100.

Angle in degrees	Tangent	Angle in degrees	Tangent	Angle in degrees	Tangent
1	·017	21	·384	41	·869
2	·035	22	·404	42	·900
3	·052	23	·424	43	·933
4	·070	24	·445	44	·966
5	·087	25	·466	45	1·000
6	·105	26	·488	46	1·036
7	·123	27	·510	47	1·072
8	·141	28	·532	48	1·111
9	·158	29	·554	49	1·150
10	·176	30	·577	50	1·192
11	·194	31	·601	51	1·235
12	·213	32	·625	52	1·280
13	·231	33	·649	53	1·327
14	·249	34	·675	54	1·376
15	·268	35	·700	55	1·428
16	·287	36	·727	56	1·483
17	·306	37	·754	57	1·540
18	·325	38	·781	58	1·600
19	·344	39	·810	59	1·664
20	·364	40	·839	60	1·732

APPENDIX VII

THE USE OF GRAPHS

When, as a result of a number of measurements, interdependent data have been collected, they may be collated and tabulated in order to make it possible for conclusions to be drawn from them. In many cases, however, even when the data have been condensed and arranged in the best manner possible in tabular form, a full interpretation of their significance is difficult or impossible from the table. In such cases an alternative method of representation is to mark each item on section paper in accordance with its position in relation to two rectangular co-ordinates—representing the two variables on which it is based—and then to draw a connecting graph illustrative of the facts presented by the data as a whole. Thus the table below contains the ages and mean heights for these ages of a number of even-aged pine woods.

Age	Height	Age	Height
10	9 feet.	33	39 feet.
10	14 ,,	35	42 ,,
10	12 ,,	37	47 ,,
12	13 ,,	38	42 ,,
15	17 ,,	38	42 ,,
15	22 ,,	39	45 ,,
17	22 ,,	40	47 ,,
18	26 ,,	41	47 ,,
21	29 ,,	42	49 ,,
24	32 ,,	42	50 ,,
25	33 ,,	44	52 ,,
25	30 ,,	46	52 ,,
28	36 ,,	48	53 ,,
29	33 ,,	48	54 ,,
30	38 ,,	50	57 ,,
31	37 ,,		

It is desired to use these data to forecast the height which other pine woods will attain in a certain time. It is clear that no average height for age can be obtained from this table.

Fig. 38 shows the data in question transferred to a graph. It will be noted that the graph is required to represent the relations between two variables—Age and Height. The variable which increases or decreases by definitely determined arbitrary amounts is known as the independent variable and is always plotted on the horizontal axis, known as the abscissa. The other variable, which depends on the movements of the former, is known as the dependent variable, and is plotted on the perpendicular axis, known as the ordinate. Where the abscissa and the ordinate meet is known as the point of origin. Time provides the best example of an independent variable; thus in *Fig.* 38 time is represented by age flowing on at a steady rate, whilst height increases at a varying rate. Each item in the table is represented by a dot at the appropriate distance from the abscissa and ordinate respectively. If any item is repeated so that two or more dots coincide in position, then the number of item represented by such a dot should be marked against it so that due weight may be given to the same in

the subsequent drawing of the curve (*e.g.*, age 38 height 42 feet, repeated twice). All the data having been entered, a smooth curve is drawn, following as closely as possible the general trend of these dots. In drawing the curve we shall be assisted by our knowledge of the manner in which height increment in an even-aged wood takes place and such knowledge may enable us to continue the curve slightly beyond the limits for which data are available. For example, the knowledge that height growth is very slow in the early years of life indicates the form of the curve from 0 to 10 years of age, whilst the knowledge

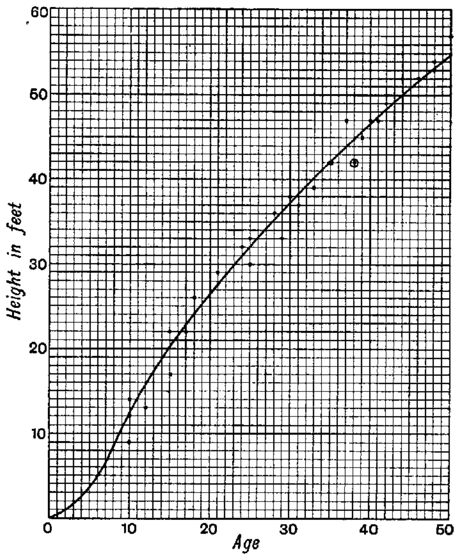


FIG. 38. Age-height graph. A ringed point indicates two coincident measurements.

that at 50 years of age the height increment, though it falls off, shows no abrupt change indicates the trend of the curve for a few years more. The average height of a wood at any age can now be read from the graph by following up the vertical line from the age on the abscissa to its intersection with the curve and following along the horizontal line from that point to the ordinate.

Checking the accuracy of the curve.—The following table of deviations may be prepared for the curve as a whole. Where the actual reading exceeds the reading on the curve the deviation is considered positive and vice versa.

Age	Height		Deviation		Age	Height		Deviation	
	Actual	From curve	+	—		Actual	From curve	+	—
10	9	11		2	33	39	40		1
10	14	11	3		35	42	42		
10	12	11	1		37	47	44	3	
12	13	15		2	38	42	45		3
15	17	19½		2½	38	42	45		3
15	22	19½	2½		39	45	45½		
17	22	22½		½	40	47	47		
18	26	23½	2½		41	47	47½		
21	29	27	2		42	49	48½	½	
24	32	30½	1½		42	50	48½	1½	
25	33	31½	1½		44	52	50	2	
25	30	31½		1½	46	52	52		
28	36	35	1		48	53	53		
29	33	36		3	48	54	53	1	
30	38	37	1		50	57	54½	2½	
31	37	38		1					
			16	12½				10½	8
								16	12½
								26½	20½

The average error of estimate is the sum total of the deviations, disregarding signs, divided by the number of observations, *i.e.*, $\frac{47}{31}=1{\cdot}5$ feet. Thus 1·5 feet is the average error to be expected in applying the graph to the determining the heights for ages of other woods. To check the fitting of the curve the average net deviation must be determined. It is $\frac{26\frac{1}{2}-20\frac{1}{2}}{31}=+\ \frac{6}{31}\ =+0{\cdot}19$ feet, indicating that the curve should be raised by 0·19 feet; this amount is too small to take into consideration since heights are generally measured only to the nearest foot.

It is possible, however, that, whilst the general fitting of the curve may be correct, it may be defective in some part. To determine whether this is the case divide the curve into a number of parts, say 0—20 years, 20—35 years, 35—50 years. The deviations are as follows :—

	+	—	No. of observations	Average.
0–20 years	9	7	8	$\frac{2}{8}=0{\cdot}25$ feet.
20–35 years	7	6½	10	$+\ \frac{1}{10}$ of $\frac{1}{2}=0{\cdot}05$ feet.
35–50 years	10½	8	13	$+\ \frac{1}{13}$ of $\frac{5}{2}=0{\cdot}19$ feet.

The division of a curve into separate parts for the purpose of checking its fit must be done with discretion, since the division arbitrarily limits the effect of individual readings to a certain part of the curve and fitting different parts of the curve separately may give absurd results, particularly if the data are few.

The section paper selected for a graph should be graduated so that the points can be shown with an accuracy equal to that with which the field measurements are made; since height measurements are generally made to the nearest foot, the graduations in *Fig.* 38 are suitable in this respect. The relations between the scales of the abscissa and ordinate should be such that the average slope of the graph should not greatly differ from 45°, since on a steeply sloping curve it is difficult to read the dependent variable accurately. The slope may be flattened by increasing the scale of the abscissa or steepened by decreasing it.

The advantages which the graphic method of portraying data possesses over the method by tabulation may be briefly stated as follows:—

(a) Every measurement taken influences the whole series of results instead of only the figures in its own class.

(b) In many cases the picture presented by a graph conveys information in a more easily assimilated form than is the case with a table.

(c) Inconsistencies or inaccuracies in measurements are more likely to be detected.

(d) Where data are incomplete, intermediate values, and in some cases values outside the limits of the data available, can be obtained from a graph.

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